

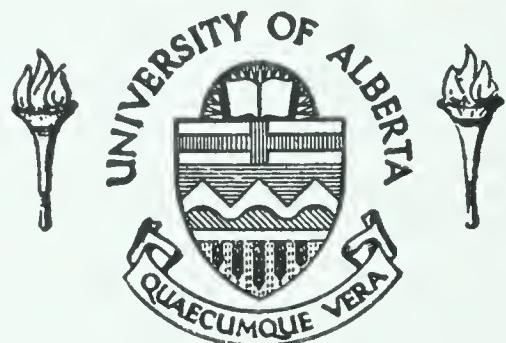
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THE UNIVERSITY OF ALBERTA

AN EVALUATION OF SOIL PROFILE DEVELOPMENT
IN SOME PEACE RIVER SOILS

by

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A THESIS

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The undersigned certify that they have read,
and recommend to the Faculty of Graduate Studies for
acceptance, a thesis entitled "An Evaluation of Soil Profile
Development in Some Peace River Soils" submitted by
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requirements for the degree of Master of Science.

ABSTRACT

In the Peace River area of northern Alberta difficulty has been encountered in adopting the new Canadian Classification Scheme to a series of soils which reflect varying degrees of profile development. The soils are found under similar environmental conditions with the dominant vegetation being aspen poplar, mixed grasses, and small shrubs. The topography in the areas where the soils occur is complex and often referred to as "humpy". The variation in profile development ranges from almost Orthic Regosol to Orthic Grey Wooded. The soils under study are at present mapped as the Judah and Kathleen series by the Alberta Soil Survey, Research Council of Alberta. The Judah series exhibits the greatest variability in profile development, whereas the Kathleen is much more uniform consistently having an Orthic Grey Wooded profile.

The objectives of the study were to determine the mode and amount of development of these soils, to classify them according to the Canadian Classification Scheme and propose modification for the Scheme for better differentiation of transitional soils.

For the investigation, six profiles were sampled which reflected morphologically the transition from the Regosol to the Orthic Grey Wooded. The profiles were sampled on a horizon basis. Physical, chemical, and mineralogical analyses were conducted in order to characterize the soil profiles under study and confirm their field identification.

The amount of profile development was also determined.

The analyses showed that all the soils under study had a definite Bt horizon of clay accumulation. The chemistry of the solum and clay mineral content were found to be similar to Grey Wooded soils in Alberta. Light mineral analyses indicated there was little loss of feldspars from the sand fraction as a result of weathering, even though a considerable portion of the feldspar content had been weathered out from the sola. The calculations involved in evaluation of profile development indicated that erosion from these soils had occurred.

The soils were classified into two Orders and three Sub-groups. The Judah series was classified as belonging to both the Chernozemic and Podzolic Orders and Orthic Dark Grey Chernozemic and Dark Grey Wooded Sub-groups. The Kathleen series was classified as belonging to the Podzolic Order, Orthic Grey Wooded Sub-group. It was believed that with continued grass vegetation, the Judah series would evolve to Orthic Dark Grey Chernozemic soils.

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TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. LITERATURE REVIEW.	6
Concepts of Braunerde	12
More Recent Concepts of Braunerde and Related Soils	19
Soil Development.	24
III. MATERIALS AND METHODS.	31
Materials	31
Methods	34
IV. RESULTS AND DISCUSSION	46
Physical Analyses	61
Chemical Analyses	67
Mineralogical Analyses.	70
V. DISCUSSION OF PROFILE DEVELOPMENT.	86
Introduction.	86
Evaluation of Profile Development for Soils under Study	90
VI. SUMMARY AND CONCLUSIONS.	102
VII. BIBLIOGRAPHY	106

LIST OF TABLES

	<u>Page</u>
I. Profile Description of Site 1	35
II. Profile Description of Site 2	36
III. Profile Description of Site 3	37
IV. Profile Description of Site 4	38
V. Profile Description of Site 5	39
VI. Profile Description of Site 6	40
VII. (a) Physical Analyses of Site 1	47
(b) Physical Analyses of Site 2	48
(c) Physical Analyses of Site 3	49
(d) Physical Analyses of Site 4	50
(e) Physical Analyses of Site 5	51
(f) Physical Analyses of Site 6	52
VIII. (a) Some Chemical Analyses of Site 1	53
(b) Some Chemical Analyses of Site 2	54
(c) Some Chemical Analyses of Site 3	55
(d) Some Chemical Analyses of Site 4	56
(e) Some Chemical Analyses of Site 5	57
(f) Some Chemical Analyses of Site 6	58
IX. Clay Mineral Distribution in Soils under Study . .	59
X. Quantitative Estimates of Light Minerals	60
XI. (a) Profile Evaluation for Site 1	91
(b) Profile Evaluation for Site 2	92
(c) Profile Evaluation for Site 3	93
(d) Profile Evaluation for Site 4	94
(e) Profile Evaluation for Site 5	95
(f) Profile Evaluation for Site 6	96

LIST OF FIGURES

	<u>Page</u>
1. Map of the Sampling Site in the Peace River Area.	33
2. Clay Distribution in Soil Profiles at Sites 1 and 2	62
3. Clay Distribution in Soil Profiles at Sites 3 and 4	63
4. Clay Distribution in Soil Profiles at Sites 5 and 6	64
5. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 1	71
6. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 2	72
7. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 3	73
8. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 4	74
9. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 5	75
10. X-ray Diffraction Patterns of Glycolated and Heated Fine Clay of Site 6	76
11. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 1	77
12. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 2	78
13. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 3	79
14. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 4	80
15. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 5	81
16. X-ray Diffraction Patterns of Glycolated and Heated Coarse Clay of Site 6	82

I. INTRODUCTION

The mapping of soils in the Peace River district of northern Alberta has presented many interesting problems to the pedologist. One of the main problems is the difficulty encountered in adopting the new Canadian Classification Scheme to a series of partially eluviated soils in this region which appear to reflect varying degrees of profile development. The soils proposed for use in this study occur under similar environmental conditions but still exhibit varying degrees of profile development, forming a transition from almost Orthic Regosol to Orthic Grey Wooded. There have been a number of suggested pathways of development proposed for these soils, namely:

1. Orthic Regosol - Regosolic Dark Grey Chernozemic
 - Dark Grey Wooded - Orthic Grey Wooded.
2. Mull Regosol - Orthic Brown Forest - Degraded Brown Forest-Dark Grey Wooded - Orthic Grey Wooded.
3. Mor Regosol - Orthic Brown Wooded - Degraded Brown Wooded - Orthic Grey Wooded.
4. or a pathway, as above, without proceeding to the Orthic Grey Wooded but remaining in a state of dynamic equilibrium at one of the intermediate stages of development.

For the investigation, the two main series under study were the Judah and Kathleen, as mapped by the Alberta Soil Survey, Research Council of Alberta. The Judah series exhibits the greatest variability in development; while the

Kathleen series is much more uniform, consistently having an Orthic Grey Wooded profile. The Kathleen series represents the end member of the first three proposed pathways for soil development since it is found under similar soil forming conditions as the Judah series. To date no Brown Wooded or Brown Forest soils have been mapped on the reconnaissance surveys conducted in the study area, although they have been identified in small areas in recent observations (38).

The soils of concern in this study are developed from lacustrine materials. The texture is usually silty clay loam and the soils are associated with a complex type of topography (often referred to as humpy) in the proximity of the Peace River. Originally the Judah series was mapped as a Degraded Black or Brown Forest (Braunerde) soil (54) because of its brown colored surface horizon and the brown textural sub-soil. There is also a gradual greying in the lower part of the A horizon rather than a distinct Ae. Due to these characteristics they differ from other degraded black soils in the area and consequently were thought to resemble Brown Forest soils. Three Orders are under consideration at the present time, namely: Brunisolic, Podzolic, and Chernozemic for classification of the Judah series*. The parent material of these soils is stratified and the greater portion of the strata consist of brown to greyish brown silty clay loam to silty clay. The remaining thinner strata consist of yellowish brown silt loam. Glacial till, lacstro-till or lacustrine material usually underlies this deposit at variable depth.

* Canadian Classification Scheme.

The dominant type of vegetation, at present, is second growth aspen poplar at the base of the slopes, and small shrubs and grasses on the crown, suggesting that no climax vegetation has been established. The areas where these soils are found have a history of previous forest burning as evidenced by the remains of burned stumps found in the area. Although the soils of the study area appear to have formed under similar environmental conditions, there is great variability in the amount of development exhibited.

One of the outstanding differences observed is the variability in thickness of the A horizon at any one site and also between sites examined. Generally the A horizon is thinner toward the crown of the hump than towards the base. The variation in depth of the A horizon can possibly be explained by the amount and length of time grasses have been growing in some areas (causing retro-gradation) contrasted with other areas where the predominant vegetation is aspen poplar with limited grass growth (causing degradation). It was found that the humps which were predominantly grassland had greater depth of A horizon than humps which were largely forested. The depth of A horizon may have been influenced by repeated burning of the native vegetation. This could possibly have induced accelerated erosion on the humps, since the slopes vary from approximately 7 per cent to as much as 18 per cent. Accelerated erosion could constantly remove the surface of the profile as the soil formed, thereby disturbing the normal sequence of development

and maintain a dynamic equilibrium at what would appear to be an intermediary stage of development.

The amount of A horizon present is rather critical in the study of these soils, especially since the new Canadian Classification Scheme separates Brown Wooded, Brown Forest, and Rego Chernozemic soils partly on this characteristic. If accelerated erosion occurs there would be very little development of A horizon taking place and as a consequence these soils would be placed in the Brunisolic Order.

It was felt that the pathway of development of these soils can best be established by conducting chemical, physical, and mineralogical analyses on samples of various profiles to corroborate evidence collected during field inspection.

The importance of such a study has implications far more reaching than those required exclusively for classification purposes. Accompanying the development of Grey Wooded soils, there is a gradual depletion of essential nutrients from the surface of the soil solum caused by weathering and leaching. For example, mineral weathering under acid conditions results in a rapid depletion of apatite, feldspars, etc. from the weathering zone, thereby decreasing the total phosphorous, potassium, etc. content of the soil. Similarly, mineralization and loss of organic matter from the soil is responsible for nitrogen depletion.

The objectives of this study are three-fold:

1. To evaluate the mode and amount of development of the particular soils under study.

2. To classify the soils included in the study according to that outlined by the Canadian Soil Classification Committee.
3. To suggest possible modifications of the scheme in order to give a better basis for differentiating between Regosolic, Brunisolic, and Podzolic soils.

II. LITERATURE REVIEW

Early concepts of soils were comprised largely of two schools of thought. One was the purely chemical and physical view of soil as a plant growing media held by such early workers as Berzelius, Liebig, Thaer, Davy, and Schubler. The other view was the geological discipline proposed by Hausman, Spengel, Cotta, Girard, Werner, and Berendt. It was not until 1850 that Fallou, in Germany, attempted to treat soil science as an independent science and soil as an entity in itself. His concept of soils included the decomposition and disintegration of native rock, with an admixture of organic materials. However the rock had changed and metamorphosed in its form and composition. Fallou stated, "soil as such does not therefore belong any more to the rock formation, but is a formation by itself" (32). Many other early workers attempted a more precise definition of soil but it was not until the time of Dokuchaev (1886), a geologist by training, that the complex of natural agencies responsible for the processes of soil development were fully appreciated. His concept of soil as a formation differs from geologic formations for it is governed by natural laws in the same manner as are living organisms. With this point of view Dokuchaev formulated the fundamental concept named by Zakharov as "the first soil axiom" that soil is a distinct, independent, and a natural-historical body.

Dokuchaev proposed that soil is a result of the combined activity and influence of climate, vegetation, topography,

parent material, and time. Climate and vegetation are considered as the active factors of soil formation, supplying the energy for soil forming processes. Topography and parent material are the passive factors behaving as source or original material and distributing agent of other processes. Time is necessary to elapse in order for the factors to manifest themselves and attain a dynamic equilibrium (32, 40, 63). Dokuchaev's early work inspired many other soil scientists of his time to look at soils more objectively.

The ideas brought forth by Dokuchaev and his classification scheme gave rise to many other taxonomical systems for soils. Sibertsev, a student of Dokuchaev, expanded on Dokuchaev's zonal classification of soils and this scheme remained in vogue for a long time in Russia, but because of the geographical bias, Glinka formulated another system based on soil formation independent of geographical location (32). Glinka's leading idea was that the principal regulator of the dynamic phenomena contributing to soil formation is the degree of humidity prevailing in the soil. Gedroiz's system, in later years, was based upon the character of the adsorbing complex of the soil and was therefore largely genetic. This scheme, however, did not include all the soils commonly found. In recent years an increasing number of American soil scientists have accepted the Russian system of classification and are endeavouring to eliminate the defects of the earlier concepts.

In 1928 Marbut, one of the earliest "American pedologists", based his classification on various Russian soil types, but his system was based entirely on characteristics of the soil itself and not on factors outside the soil (32, 40). However, not

having found a satisfactory classification scheme among these earlier works, soil scientists today are still advocating new systems and modifying older ones.

The most recent attempts at suitable classification schemes are now on a universal basis, in contrast to the previous local schemes. Baldwin, Kellogg, and Thorp (5) of the U.S.A. in 1949 devised a scheme which was a modification of Marbut's system and essentially returned to the zonality concept of Sibertsev.

In France, Aubert and Duckafour proposed a world wide classification system (3). This system was essentially a genetic classification based on two fundamental characteristics of soil development:

1. degree of development marked by profile horizon formation
2. physical and chemical nature of development
 - (a) conditions of alterations and weathering of parent materials
 - (b) type of humus
 - (c) chemistry of adsorbing complex.

This system, although comprehensive, has the drawback in that the genetic bias makes it impossible to categorize many soils of the world if their genesis is not known.

In 1958 Russian soil scientists (Ivanova and Rozov) advocated a new soil classification scheme where the basic unit was the genetic type of soil distinguished by:

1. internal properties of the soil
2. processes of formation and their determining factors.

There was also a greater emphasis placed upon the agronomic properties of the soils involved than by previous schemes (28, 82).

The most radical change in soil classification has come about with the 7th Approximation of the U.S.A., where a natural classification of the world's soils was attempted, under the direction of Dr. G. Smith. This was the first system completely breaking away from older, often ambiguous, soil terminology and introducing newer, more precise nomenclature for purposes of soil classification (65).

In Canada, there has been no attempt at a world wide scheme but rather a comprehensive national system of classification closely linked to the U.S.A. classification. The Canadian system was based on both morphology of the soil profile and genesis of the soil. There are six levels of abstraction in this scheme, closely correlated with the categorical levels in the U.S.A. (65). The highest level of abstraction was the Order of which six were recognized, namely: Chernozemic, Solonetzic, Podzolic, Brunisolic, Regosolic, and Gleysolic. The possibility of including a seventh Order for organic soils is at present under study. Orders or Category VI consisted of a number of morphologically and/or genetically related soils, the result of environmental processes.

The Orders were subdivided into Great Groups or Category V. This subdivision used various criteria for differentiation depending on the Order it was characterizing. Largely the differentiation was based on a horizon basis which reflect the influences of the soil forming factors, for example:

the Great Groups in the Chernozemic Order are differentiated on the color of the surface horizon, the Great Groups in the Podzolic on the nature and type of B horizon, the Brunisolic Great Groups were subdivided on the type of A and B horizons, etc.

The Great Groups were comprised of Sub-groups, which represent the modal and intergrade concepts of the respective Great Group. The Sub-groups incorporated all the soils within the Great Group which showed slight differences in kind of development.

The lower three categories (Family, Series, and Type) were based largely on morphological features of the soils. Family was defined as morphologically related soils with slight variation in the degree or intensity of development. The Series was considered the basic unit of classification and defined as a group of soils developed from the same kind of parent material, by the same genetic combinations of processes and whose horizons are quite similar in arrangement and general characteristics. The lowest category was based on the texture of the surface horizon and thus Type may be considered the textural class of the Series.

With this system, as with the others, difficulty was encountered in characterizing all the soils occurring on the national level, because of the problems involved in categorizing a natural body by a rigid classification scheme (50).

Most classification schemes, to date, had a natural tendency of placing major emphasis on the soil profile. Soil

profiles evolved to the point where they occupy single points on the earth's surface. It should be remembered that since soils are natural bodies they have shape and area, breadth and width, as well as depth. That is to say, soils are dynamic not only as individual profiles but also as landscapes. Many types of unique soils exist in the world. There are also gradations between all these unique types produced by various combinations of the soil forming factors. Thus, since soils occur as a continuum the problem of categorizing all the various soil types and gradations between them exists.

There have been many classification schemes proposed but none universally adopted. Accompanied with the problems of profile descriptions and language barriers, similar soils have been designated differently in different countries.

A look at a world soil map will show that many transitional soils occur between the well established great soil groups. In general, one passes from tundra in the north to true Podzols, to Brown Forest, to Forest Grey Brown, to Degraded Chernozems and Chernozems, to Brown and Yellow soils, and finally into Red soils, as one progresses southward. In Alberta's northern and central portions we pass from Grey Wooded to Chernozems going from north to south with Brunisolic (Braunerde of Europe) and Degraded Chernozemic as intergrade types. For a better understanding of these latter types of soils and in order to have an appreciation of these soils throughout the areas where they occur a discussion of these types is presented.

Concept of Braunerde

The first group of soils named in the transitional areas between Chernozemic soils and Grey Wooded was the concept of Braunerde by Ramann in 1905 (69). Ramann stated that "Braunerde are the most widely distributed soils in Central Europe. They are the products of a temperate climate and moderate leaching. The soluble salts including sulfates and carbonates are leached from the upper soil layer. Due to the presence of iron hydroxide, the soil is yellow to deep brown or if the parent material is red the soil is red, brownish red to reddish brown. The content of humus varies considerably but is still sufficient, because of its dark color, to impart to the soil a dirty unclean tint." In his definition of Braunerde, Ramann did not clarify whether the soils do or do not have a textural B horizon or horizons of clay accumulation. Thus some pedologists felt that Ramann's Braunerde had no illuvial horizon of silicate clay minerals. However, when Ramann described the distribution of Braunerde in France, England, Germany, Austria, southern Sweden, and parts of central Russia, he stated that the zone of distribution narrows to the east and is limited by the Urals. It becomes evident that he included soils with and without textural B horizons. The general definition given by Ramann permitted vastly diverse soils to be labelled as Braunerde by different workers and the name quickly came into general use.

In eastern Europe the term Braunerde was quickly adopted and many studies were published on the genesis and distribution of these soils. Murgoci (69, 63) in 1909 appeared

to have been the first to use Ramann's term and also to have coined the term "Brown Forest" as a synonym. He pointed out that these soils were widely distributed and occurred in areas where the forest had invaded the zone of Chernozems. Under the forest influence the soils lost their original character and were transformed into Degraded Chernozemic or into Brown Forest soils. Murgoci drew a distinction between Braunerde and the Russian Podzol or the German Bleicherde. His Braunerde always occur under oak forest; while the Podzol occur under beech forest. Murgoci's definition of Braunerde included a humus content of 3 to 5 per cent with the soluble salts including carbonates being leached from the upper soil to a depth of a metre or more. Angular blocky structure was very apparent in the subsoil where the color was slightly redder due to the presence of concretions and skins of iron oxide. Murgoci further pointed out that Dokuchaev had shown earlier the existence in Bessarabia of soils which he called "Brown soils of the oak forest". There was therefore a distinction made between Brown Forest and the soils of the dry steppes of Russia. Thus Brown Forest was a separate entity. The soils of the Russian forest degraded steppe was called Grey Forest, by Murgoci.

Glinka (1911) was not inclined to consider Braunerde as a new great soil group (69). He claimed that Braunerde was characterized by the same horizon sequence as the Podzol and consequently was a "variety" of the Podzol having an illuvial B horizon. In essence Glinka believed that the Braunerde of Ramann was simply a Degraded Chernozem of forested areas

developed upon calcareous parent materials. The brown color of the illuvial horizon was believed to be due to decalcification. He postulated that in the formation of the reddish brown horizon the iron migrates with the soluble humus compounds and that after the fixation of the iron, lime was leached to greater depths. The lime was reprecipitated with humus as CaCO_3 . He felt that the presence of CaCO_3 in the parent material was necessary for the formation of both Grey Forest and Brown Forest (Braunerde) soils. Another requirement for developing a soil (solum) with reddish brown horizons was the presence of a deciduous forest vegetative cover.

Stebutt (69) in Germany stated that the characteristic feature of Braunerde was the high degree of silicate weathering with a slight eluviation and illuviation of sesquioxides and silica gels. For this reason the soil did not have a bleached color but exhibited a characteristic "dirty brown color". The dynamic system of the Brown Forest, he believed, was not stable but may easily turn in the direction of podzolization or to the formation of Red Earths.

De Sigmund (in 1938) made a distinction between Brown Earths (Braunerde) and Brown Forest soils (63). He considered Brown Forest to be a forest soil of the Podzolic type (temperate zone) in which the eluvial horizon could not be detected by the naked eye. He further stated that Brown Forest soils were formed under beech forest where the leaf-fall decays rapidly and produces a mild humus (probably referring to Grey Brown Podzolic). On the other hand, Brown Earths were forest soils

of the temperate zones in which the Ae horizon was replaced by an accumulation horizon of brown ferric hydroxide.

In 1924 Fosterus, in the Scandinavian countries, advocated the following concept of Braunerde: "Dirty brown color due to the mixing of iron oxide and humus; lime and potash are leached while the sesquioxides remain or are precipitated on the surface" (69). Lundbland (1924 and 1934), another Scandinavian worker, did not share the idea expressed by Glinka that the presence of CaCO_3 in the parent material was necessary for the formation of Braunerde (69). He suggested vegetation and the consequent type of humus was the major factor in the formation of Braunerde. Under vegetative cover of beech, oak, and mixed oak, one found Braunerde while Podzols were characteristic of the coniferous forests. The basis for his argument was that in the best beech forest mull, the organic matter content rarely reaches 10 per cent. In the mull horizon of coniferous forests, with rich forest floor, the organic matter content may reach 50 per cent. Tamm earlier in 1923 had demonstrated the occurrence of Braunerde and had shown that Braunerde very quickly changed if beech forest was replaced by conifers (69). Tamm also stated that the Brown Earths were the climatic soil types in southern Sweden. These brown soils can develop from lime rich as well as lime deficient parent materials. From the literature it was suggested that Lundbland and Tamm consider Braunerde analogous to the Brown Podzolic soil of the U.S.A. or Acid Brown Forest in Canada.

In the British Isles, Brown Earth or Brown Forest soil was generally considered as a soil without definite eluvial or illuvial horizons. Russell (62) stated that the Brown Earth profile consists of an "upper layer containing neutral to almost neutral humus, pH may be as low as 5 but generally 6 to 7 underlain by a layer of brownish colored soil 50 cm. or so deep, cracking horizontally and vertically when dry and having a good crumbly structure". Kay (1937) differentiated between Brown Earth and podzolized soil by the composition of the clay fraction (62). This was usually constant throughout the Brown Earth. In contrast, in podzolized soils a relatively siliceous A horizon overlaid a B enriched in sesquioxides from above. Robinson (1949) placed the Brown Earths in the Podzolic group and thus they appear to be our concept of Grey Brown Podzolic. Their similarity with Podzols consisted in the complete leaching of carbonates from the mature soil profile. They differed from Podzols chiefly by their higher base status and in their structure. A number of other workers (Clarke, Jacks, etc.) felt that the term Brown Earth was much too comprehensive and suggested that it should be restricted to soils formed under deciduous forest where the most typical variety, under these conditions, would be described as Brown Forest. Their description was essentially as follows: There were no visible boundaries between the A and B horizon. The color changed uniformly from dark brown or black of the mull horizon, to a light brown at the indefinite boundary between the soil proper and the parent rock. The mull layer was rather acid (pH 4.5 to 6.5) and sometimes showed a slight accumulation of iron and aluminum oxide (4, 62).

In Germany the concept of Braunerde was similarly very controversial after its introduction by Ramann. Stremme (69) disagreed with Glinka's concept of Braunerde being a degraded Chernozem. Stremme and co-workers stated that the characteristic feature of Brown Forest was the presence of a brown B horizon. The color was attributed to iron oxide and occasionally also to humus. The presence of a bleached horizon was confined to non-calcareous parent materials. For a short period the term Braunerde was not used. However, Kubiena in 1948 and later in 1953 re-introduced the term. He considered Braunerde as neutral to moderately acid A (B)¹ C soils of temperate climates with predominantly immobile flocculated colloidal substances; the brown to light ochre colored B horizons were not enriched horizons but have been formed by deep reaching chemical weathering, with good aeration and abundant but not excessive moisture. Kubiena divided the original Braunerde, described by Ramann, into the Braunerde, the Podzolic Braunerde, and the Braunlehm (tropical areas).

The term Braunerde (Sol brun, Terra brune, Tierra parda) was first applied in France and adjacent countries to any type of brown soil without further distinction. In 1928 Agafonoff described the Braunerde of Ramann as a podzolic sub-type intermediate between the typical Podzol and the Yellow-Red Mediterranean soil (69). Some other workers (Tavernier and Smith) later placed Braunerde as a transition between Podzols and Chernozems stating that these soils had a tendency to become

¹ (B) denotes incipient B horizon

brown because of the organic substances, upon decomposition generally give a brown humus. Aubert in 1938 grouped the Brown soils into three genetic series, namely: Rendzinias (calcareous), Sols Brun (Brown Earth), and Sols Lessive's (leached Brown) (32).

In the United States the concept of Braunerde was introduced by Marbut in 1927 using the term Brown Forest as a synonym (48, 69). He did not define the term but did say that they were dominant in the mid-latitude belt of eastern United States. The term Brown Forest soils was re-introduced by Baldwin et al. in 1938 for a group of soils dominantly saturated by calcium, lacking eluvial and illuvial horizons and developed in temperate humid regions under forest vegetation (5). These workers felt that Brown Forest soils were calcimorphic and corresponded to Ramann's original Braunerde and were to be distinguished from the associated Grey Brown Podzolic soils by a lack of evidence of podzolization. The Brown Forest soils were slightly leached but had not developed eluvial or illuvial horizons to any appreciable extent. In 1938 Baldwin et al. also introduced two other great groups thus recognizing three great soil groups:

1. Grey Brown Podzolic
2. Brown Podzolic
3. Brown Forest,

within the group originally designated Brown Forest by Marbut (5).

More Recent Concepts of Braunerde and Related Soils

With increased knowledge of soils, accompanied by more extensive laboratory and field studies, new classification schemes had arisen. Each of these schemes had a local bias dependent upon the soils they were attempting to categorize. Although great advances had been made in soil classification, terminology, and genesis, similar soils were still classified differently and consequently called by various names in different countries.

Joffe (32) stated that such soils as Braunerde, Grey Forest, and degraded Chernozems were merely temporary which could give way to podzolization and thereby evolve to true Podzols.

A review of the recent Russian literature (37, 61, 82, 83) exhibited two major groups of soils in the transitional zone between true Podzols and Chernozems. These were the Grey Forest soils (and the associated Sod-Podzolic soils) and the Brown Forest sub-types. The Grey Forest soils were considered as Chernozems which have been invaded by forest or the prairie steppes encroaching into the forested regions. Zahkarov (82) stated these soils were formed under the influence of deciduous trees as a transitional belt between the steppes (Chernozems) and the Taiga-forest (Podzol) zones. That is, the soils were developed under birch or birch-pine vegetation occasionally mixed with aspen forest. There was often a dense tall herbaceous grass understory tending to bring about sod

formation on the surface. Carbonates were evident in the parent material. A definite podzolization process was recognized and thus the profile was differentiated by the degree of podzolization into:

1. Dark Grey Forest (weakly podzolized)
2. Light Grey Forest (strongly podzolized)
3. Grey Forest (intermediately podzolized).

A sub-type of the Russian Derno Carbonate soils, the podzolized Derno Carbonate was also found in areas dominated by coniferous and deciduous tree species and were often associated with Grey Forest soils. In these areas the forest was sparse and there was a good herbaceous cover. Horizon differentiation was well exhibited with an eluvial A, an illuvial B horizon, and a zone of calcium carbonate accumulation. These soils were believed to be only temporary and could evolve in two directions of development:

1. podzolization -- under forest vegetation with the formation of Grey Forest soils
2. steppe formation -- into thin Chernozem soils.

The Sod-Podzolic soils (37, 76) formed under the influence of grass meadow vegetation was very similar to the Grey Forest soils and was often found in association with the latter. These soils according to Korotkov (37) were Podzolic soils formed where grassland had initiated the formation of sod, i.e. retrogradation. Sod was formed by the synthesis and accumulation of organic, organo-mineral, and mineral colloids accompanied by accumulation of plant nutrients.

Due to the high ash content of grass roots and high amounts of Ca, P, Si, Al, and Fe, cations accumulated in the root zone even under a leaching type of regime. This promoted a formation of more condensed forms of humic substances causing the gradual accumulation of colloidal particles and synthesis of clay minerals.

The true Brown Forests of Russia were exemplified by absence or weak indications of podzolization. Generally, these soils were developed upon a calcareous parent material and were essentially similar to the Canadian Brunisolics. Four principal sub-types of Brown Forest soils are recognized:

1. Typical -- solum base saturated
2. Residual calcareous -- calcareous parent materials
3. Unsaturated -- 50 to 90 per cent base unsaturated
4. Podzolized -- podzolization evident.

At the 6th International Congress of International Soil Science Society (1956), Aubert and Duckafour presented a new system of soil classification for the Brown Earths in France. The Brown Earths were essentially divided into two basic groups:

1. Brown Soils -- (Brown Forest)
2. Leached Brown Soils -- (Acid Brown Forest, Sols Lesivée).

These soils were characterized by a mull organic horizon undergoing rapid decomposition as well as a definite B horizon. The mull humus on the soil surface did not bring about degradation of clays and it was postulated that clay movement, in the Brown Earths, was mechanical leaching (lessivage).

They stated that the Brown soils or Brown Forest gave way to the Grey Forest soils in eastern Europe. These soils were developed most commonly on calcareous parent materials; on more acid parent materials "Sols Brun Acide" (Acid Brown Forest) soils were formed. The organic layer on the surface was often absent due to rapid mineralization, thereby a slightly leached horizon was formed. The Leached Brown Soils (Sols Brun Acide) lay in transition between Brown Forest and true Podzols. When the former soils became leached they were termed Sols Lessivée (i.e., Leached Brown Forest Soil). The processes involved in leaching were definitely lessivage (physical movement of clay) and not podzolization because the organic matter initiating podzolization was not present as a result of the rapid mineralization (3, 22). In this classification system there were more variations allowed in the Brown Soil group than in other schemes.

Prior to the advent of the 7th Approximation the Brown Earths in the United States consisted of Grey Wooded, Grey Brown Podzolic, Brown Podzolic, and Brown Forest, all of which were originally called Brown Forest by Marbut. These soil categories were similar to those in the Canadian classification system with the exception of the Brown Podzolic which the Canadian scheme had listed as Acid Brown Wooded. It had been suggested that the Grey Wooded soils on the North American continent were equivalent to the Grey Forest soils of eastern Europe (39). However some of the Grey Forest, because of their genesis, were probably more similar to the

Grey Brown Podzolic or Dark Grey Wooded soils on this continent. Cline (19) in 1955 recognized the occurrence of Acid Brown Earths in New York. His concept was similar to that of Sol Brun Acide described by Aubert and Duckafour. Cline further stated that these soils were similar to the Grey Brown Podzolic soils but were more strongly leached, generally more acid and lacked distinct clay accumulation in the B horizon.

Thus the difficulty involved in the classification of soils can be appreciated, especially when an attempt at a world classification of soils was strived for. The great confusion and difficulty of soil classification arose from mainly three causes:

1. The attempt to classify a natural body by an artificial system.
2. Most of the currently recognized great soil groups were named and defined before the development of a vocabulary of more precise terms for describing soils.
3. With increased knowledge of soils, more precise definitions of great soil groups were possible. We had, nevertheless, retained the old terminology and nomenclature under more exact use.

Fortunately within the last few years there has been a closer correspondence among soil scientists of the world and some of the variations in terminology were being eliminated and a much closer correlation of soil types was now possible.

Soil Development

Soil development had interested people for many years but had only been studied sporadically. More recently these studies had assumed greater importance and stress. The study of soil profile development was of prime importance for the understanding of the process active in formation of the soil solum and its constituent horizons.

In general, soil development could be defined as that part of soil formation which led to differentiation of the soil body into horizons. Prior to 1942 the study of soil development lacked a quantitative method of measurement. In that year Marshall and Haseman published the results of a quantitative study of soil development in which the change in composition of the various horizons in the soil profile was assessed against a selective resistant index mineral (zircon, tourmaline, garnet, etc., or a complete size fraction) (43). The choice of the index mineral varied with soil according to the mineralogical composition. It must be, however, relatively resistant to weathering, immobile, and consequently nonclay size.

To evaluate the development of a soil profile it was necessary to first evaluate the initial state of the soil material in each horizon. This might be accomplished by use of the parent material as the initial state. Once the initial state was known, the amount of development could readily have been determined in terms of the mineralogical and

chemical processes occurring in the transformation of the parent material to soil.

Barshad, in Chemistry of the Soil, gave detailed procedures for the evaluation of soil development by both mineralogical and chemical means (6). He stated that soil formation was equal to losses from the profile (drainage waters leaching mineral elements) plus transformations within the profile (clay minerals and organic matter) plus gains of the profile (atmospheric water, etc.). Using Barshad's methods one is able to calculate the amount of clay migration, amount of erosion or deposition on the surface which had taken place, and consequently an attempt might be made to quantitatively evaluate profile development.

Joffe (32) in his textbook Pedology had summarized much of the work done prior to 1951. Since that date, numerous studies have been reported in the literature on soil formation as well as on sequences of development. Some of the earliest work of this type was on New York soils by Cline who suggested that on calcareous materials, under forest vegetation in New York, soil development might proceed through a series of normal profiles from Brown Forest through Grey Brown Podzolic to Brown Podzolic or Podzol soils (18). The Grey Brown Podzolic and Brown Forest soils were restricted to parent materials high in bases while the Brown Podzolic and true Podzol were generally restricted to more acid materials. Differences in vegetation were also associated with these dissimilarities in parent materials. He suggested that the extent of Grey Brown Podzolic

and Brown Podzolic soils were not correlated with measured differences in climate, but that climate was associated with the distribution of Brown Podzolic and Podzol soils on similar parent materials. It was postulated that there is a continuous sequence from Brown Forest to Brown Podzolic for a series of parent materials with progressively decreasing carbonate content. There was evidence that at least some Brown Podzolic soils have developed in the sola of former Grey Brown Podzolics. Similar work by Stobbe on some Canadian soils brought forth the same sequence of development as that found by Cline (67). The presence of the Grey Brown Podzolic soils in these areas was theorized to be caused by either processes involving a high base status or a period of climate warmer than that which exists at present (18, 67).

White and Riecken did some work on Brunizem -- Grey Brown Podzolic soil biosequences (78). These soils were found throughout the climatic tension zone occupied by the Brunizems and associated Grey Brown Podzolics. The workers suggested that the transitional soils were formed by a change in the biotic factor of soil formation, in particular the encroachment of deciduous trees onto the prairie as related to the changing climatic conditions. These transitional soils were considered to have a polygenetic origin. The authors stated further that in general the uneroded transitional soil had a thicker dark colored A horizon, weaker Ae development, and less strongly formed structural B than the Grey Brown Podzolic.

Among some of the most recent work is that of Wright et al. who reported on some alluvial soils in the Northwest Territories (80). They stated that the sequence of development of these particular soils was: Alluvial -- Brown Wooded -- Grey Wooded. The basis for their conclusions were:

1. an accompanying fall in pH as a function of depth
2. the substantial supply of organic matter in the Alluvial and Brown Wooded and the low level in the Grey Wooded soils
3. translocation of clays in the Grey Wooded, with the highest amount in the B horizon, which was not found to be true in the other two soils studied.

Reiger and Juve reported on soil development in recent loess deposits in Alaska (60). They suggested the sequence of Regosolic near the source of loess, Regosol -- Podzol intergrades further in shallower loess, and Podzols at even greater distances. The Regosolic soils were considered to be Sub-Arctic Brown Forest. The sequence was therefore Sub-Arctic Brown Forest to Brown Forest intergrade to true Podzols. It was believed that podzolization is the dominant soil forming process active in these soils.

Pawluk, in Alberta soil studies, suggested the formation of Grey Wooded soils in the northern Parkland areas of the province to be the result of invasion of aspen poplar forest vegetation onto former grassland area and consequently a degradation of the Chernozemic soils (58). Thus the sequence of development was Chernozemic -- Degraded Chernozemic -- Grey

Wooded. In the forest regions he suggested the sequence of soil development was Regosolic -- Brunisolic -- Grey伍ded as a result of leaching of soil parent materials by acidic decomposition products of the forest vegetation (aspen poplar and mixtures of aspen poplar and spruce).

Simonson stated that losses of organic matter are characteristic of the deeper A horizons of Brunizems which were invaded by forest cover and are gradually being changed to Grey Brown Podzolics (64). Moreover, the appearance and the gradual increase in depth of the Ae horizon in the profile were accompanied by a parallel decrease in organic matter. Similarly, Stobbe and Wright postulated that some of the reactions and processes which bring about Podzol development may also be active to various degrees in the formation of Grey伍ded soils (68). This further indicated the possibility of Grey伍ded soils being formed from Brown伍ded and Brown Forest pre-cursors.

It is a fairly well accepted fact that prior to appreciable translocation of humus and sesquioxides during pedogenesis, a considerable amount of the exchangeable cations from the upper horizons are displaced by H ions from the acidic decomposition of the organic matter. These replaced cations are either leached out of the profile or to lower horizons. Before any clay leaching can take place in calcareous or saline parent materials, the free lime and/or salts must be removed bringing about a dispersion of the clay and a consequent clay movement with a simultaneous accumulation in the B horizon.

Accumulation is brought about by saturation of the exchange complex with metallic cations in the B horizon or by the natural chelating substances liberated from organic matter precipitation in this horizon.

The Russian worker Zaytsev characterizing the Brown Forest soils in his country concluded that these insufficiently studied, geographically distributed soils range from undeveloped to eroded and developed types (83). On the basis of the three Brown Forest soils studied, he concluded these soils belong to two different groups, namely, the Sod-Podzolic and Grey Forest. These soils are similar to the Sod-Podzolic in the following ways:

1. accumulation of SiO_2 in top soil horizons accompanied by spontaneous loss of cations, especially Al, Mg, and secondary Fe
2. presence of acid reaction and of exchangeable H ions in the surface horizons
3. presence of a tendency toward accumulation of iron in colloidal form in the middle of the profile (B)
4. increase in total exchangeable Ca in humus-accumulation horizon compared to deeper horizons.

They are similar to Grey Forest soils in the following manner:

1. absence of definite podzolization (visibly)
2. presence of pronounced and relatively thick humus-accumulation horizon
3. presence of nutty-granular structure in the humus accumulations horizon.

Similar type of work was carried out by Bartelli and Odell who reported that the important criterion for the differentiation of soil horizons was the clay content (8). These workers studied the clay migration and accumulation of some soils of northern Illinois. They explained that the origin of the clay fraction was a key to the understanding of illuvial horizons. The clay might be (a) inherited from the parent material, (b) formed in situ, or (c) translocated from above horizons.

Some Russian workers concluded that the formation of various soils under coniferous vegetation was closely connected with changes in the biological and climatic factors (82, 84). They placed more emphasis on the environmental factors of soil formation. These same workers and others in the United States are now beginning to place emphasis on external forces, such as increasing the thickness of profile gradually by loess accumulation or the reverse (diminishing the thickness of the profile by accelerated erosion).

In summary, from the voluminous amount of literature published on this subject, one can appreciate the number of interrelated factors which must be considered in an endeavour to understand the development and classification of a particular soil profile. It can be appreciated that evaluation of profile development is important in classification of soils. This is especially true where intergradational soils must be placed into a rigid classification scheme. Therefore, the problem was undertaken to classify the Judah soils according to that outlined by the Canadian Soil Classification Committee.

III. MATERIALS AND METHODS

Sample Area

The area of northern Alberta, in the Peace River region where the soils under study are found, is characterized by a sub-humid climate. The annual precipitation is approximately 15 to 18 inches with a mean annual temperature of about 34.5° F. The highest amount of precipitation is received during the summer months with about 55 per cent of the rainfall received in rates of less than 0.10 inches per day and approximately 90 per cent in rates of less than 0.50 inches per day. The mean annual relative humidity is 70 per cent. The average annual wind mileage is about 71,200 miles. The wind velocity averages about 8.3 miles per hour and varies from an average of 7.0 miles in the winter months to 10.5 miles in May (53, 54, 56).

Generally, the native vegetation consists of mixed tree cover in which aspen poplar (Populus tremuloides) predominates. Other tree vegetation intermingled with aspen poplar is:

1. Balsam poplar (Populus balsamifera)
2. Birch (Betula papyrifera)
3. Willow (Salix species)
4. Alder (Alnus crispa)
5. Spruce (Picea glauca)
6. Pine (Pinus banksiana).

The understory and ground cover vegetation consists of:

1. Saskatoon (Amelanchier alnifolia)
2. Common wild rose (Rosa woodsii)
3. Dogwood (Cornus stolonifera)
4. Snowberry (Synphoricarpus occidentalis)
5. Reed grass (Calamagrostis species)
6. Rye grass (Elymus species).

Much of the native vegetation cover in this general area has been destroyed by fire and land settlement.

The soils in this study comprise six profiles. At present they are classified as belonging to the Podzolic Order, Grey Wooded Great Group, and Dark Grey Wooded and Orthic Grey Wooded Sub-groups, as outlined by the Canadian Classification scheme. A sequence of soil profiles was sampled in order to obtain a series of soils exhibiting the complete range of variation from the Orthic Grey Wooded to one approaching a Regosol profile. The sampling and sequence variation was based on factors reflected by morphological features.

The samples were taken from various points in the Peace River area (see Fig. 1) starting from the east at Kathleen and proceeding westward to the Doe River area, near the Alberta-British Columbia boundary. Samples were collected during the latter part of August and the first part of September, 1961. All samples were taken with a "Bull Soil Sampler" to an average depth of 50 inches. The profiles

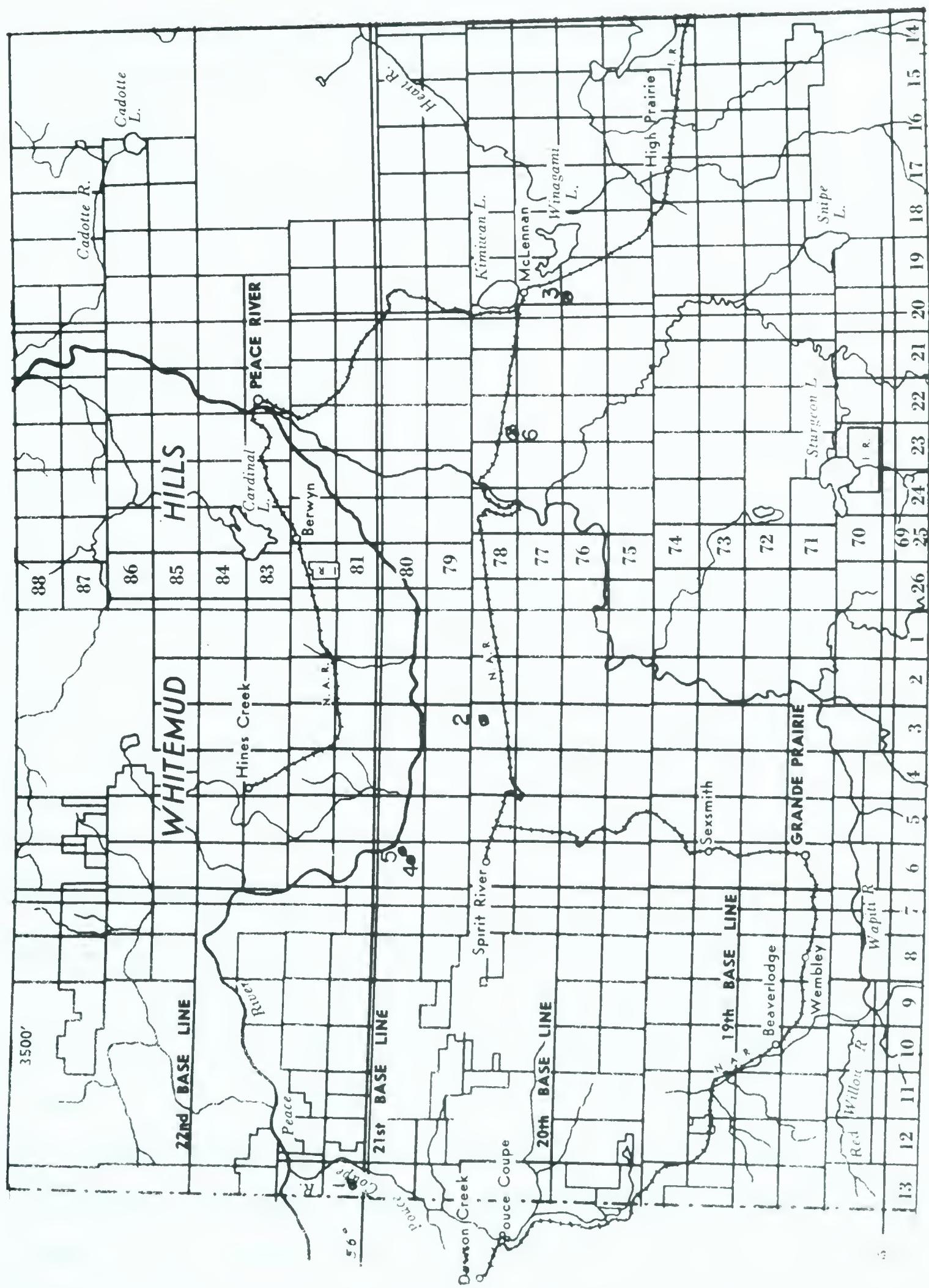


Figure 1. Map of sampling sites in the Peace River area.

were sampled on a horizon basis. Cores were taken directly in the field for bulk density determinations; these were placed immediately in plastic bags and taken to the laboratory.

Descriptions of each of the sites are given in Tables I to VI.

Methods

Preparation of Sample

Upon arrival at the laboratory, the samples were spread out and allowed to become air dry at room temperature. The samples were ground by a porcelain ball mill, to avoid iron contamination. The samples were ground to pass a 2 mm. sieve and stored in quart sealers. A portion of each sample was taken immediately after sieving for determination of hygroscopic moisture. The samples, when required for analyses, were obtained from the sealers by "quartering".

Physical Analyses

Mechanical Analysis: Mechanical analyses of the soil samples were determined by the pipette method described by Toogood and Peters (74). The fine clay content was determined by evaporating an aliquot separated from the total clay fraction by centrifugation (9). In preparation of the samples for mechanical analyses, ceramic cones with applied suction were used for the removal of soluble salts. The soils, especially the C horizons, were calcareous and thus remained flocculated.

TABLE I. PROFILE DESCRIPTION OF SITE 1

Legal Location NE 8 - 81 - 13 W6

Horizon	Depth (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	1 - 0	Very dark greyish brown	10 YR 3/2	Very dark brown	10 YR 2/2	SiCL	Sub-angular blocky, friable
Ahe	0 - 2	Greyish brown	10 YR 5/2	Very dark greyish brown	10 YR 3/2	SiC	Sub-angular blocky, friable to firm
AB	2 - 4	Light grey	10 YR 7/2	Dark greyish brown	10 YR 4/2	SiC	Sub-angular blocky, friable to firm
Bt ₁	4 - 7	Light brownish grey	10 YR 6/2	Brown	10 YR 5/3	SiCL - SiC	Sub-angular blocky, firm
Bt ₂	7 - 12	Light brownish grey	10 YR 6/2	Dark brown	10 YR 3/3	SiC	Medium to coarse sub- angular blocky, firm
BC	12 - 15	Light brownish grey	10 YR 6/2	Very dark greyish brown	2.5 Y 3/2	SiC	Weak prismatic, weak blocky, firm
C ₁	15 - 19	Light brownish grey	10 YR 6/2	Very dark grey brown	2.5 Y 3/2	SiCL	Medium blocky, firm to friable
C ₂	19 - 25	Greyish brown	10 YR 5/2	Very dark greyish brown	2.5 Y 3/2	SiCL	Medium blocky, firm to friable
C ₃	25 - 35	Greyish brown	10 YR 5/2	Very dark greyish brown	2.5 Y 3/2	SiCL	Medium blocky, firm to friable
Topography -- gently rolling with slope of about 17 per cent; sample was taken about six feet lower than crown of hump.							

* Munsell colors

TABLE II. PROFILE DESCRIPTION OF SITE 2

Legal Location NE 24 - 78 - 3 W6

Horizon	Depth (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	1 - 0	Dark greyish brown 10 YR 3/2		Very dark brown YR 2/2			
Ahe	0 - 3	Brown 10 YR 5/3		Very dark greyish brown 10 YR 3/2		SICL	Granular to fine sub- angular blocky, friable
AB	3 - 7	Pale brown 10 YR 6/3		Dark brown 10 YR 4/3		SIC	Sub-angular blocky, firm to friable
Bt ₁	7 - 13	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4		SIC	Sub-angular blocky, firm
Bt ₂	13 - 17	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4		SIC	Sub-angular blocky to coarse sub-angular blocky, firm
BC	17 - 19	Greyish brown 2.5 Y 5/2		Dark brown 10 YR 3/3		SIC	Coarse sub-angular blocky, firm
C ₁	19 - 25	Light brownish grey 2.5 Y 6/2		Dark greyish brown 2.5 Y 4/2		SIC	Sub-angular blocky, firm to friable
C ₂	25 - 31	Light brownish grey 2.5 Y 6/2		Dark greyish brown 2.5 Y 4/2		SICL	Sub-angular blocky, with sea shells, firm
C ₃	31 - 41	Light brownish grey 2.5 Y 6/2		Dark greyish brown 2.5 Y 4/2		SIC	Sub-angular blocky, firm to friable
Topography -- gently rolling to rolling with slope of about 15 per cent; sample was taken at crown of hump.							

TABLE III. PROFILE DESCRIPTION OF SITE 3

Legal Location	Depth (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	2 - 0	Dark greyish brown 10 YR 3/2		Very dark brown YR 2/2			
Ah	0 - 3	Brown 10 YR 5/3		Dark brown 7.5 YR 3/2	Sil	Granular, friable	
Ahe	3 - 6	Pale brown 10 YR 6/3		Dark brown 10 YR 4/3	Sic	Granular to sub-angular blocky, friable	
BA	6 - 8	Pale brown 10 YR 6/3		Dark yellow brown 10 YR 4/4	Sil	Sub-angular blocky, firm to friable	
Bt ₁	8 - 13	Pale brown 10 YR 6/3		Olive brown 2.5 Y 4/4	Sic	Blocky to sub-angular blocky, firm	
Bt ₂	13 - 17	Pale brown 10 YR 6/3		Olive brown 2.5 Y 4/4	C	Blocky to sub-angular blocky, firm	
BC	17 - 21	Pale brown 10 YR 6/3		Olive brown 2.5 Y 4/4	C	Coarse blocky to sub- angular blocky, firm	
C ₁	21 - 25	Greyish brown 10 YR 5/2		Dark grey brown 2.5 Y 4/2	Sic	Large blocky, firm	
C ₂	25 - 29	Greyish brown 2.5 Y 5/2		Dark grey brown 2.5 Y 4/2	Sic	Fine blocky to sub- angular blocky, firm to friable	
C ₃	29 - 36	Greyish brown 2.5 Y 5/2		Dark grey brown 2.5 Y 4/2	Sic	Laminar cleavage, root mats in channels, firm to friable	
C ₄	36 - 49	Greyish brown 2.5 Y 5/2		Dark grey brown 2.5 Y 4/2	Sic	Fine granular to sub-angular blocky showing stratification, root mats, along channels, firm to friable	
Topography -- rolling with slope of 18 to 20 per cent; sample was taken at side of crown of hump.							

* Munsell colors

TABLE IV. PROFILE DESCRIPTION OF SITE 4

Legal Location NW 10 - 80 - 6 W6

Horizon	Depth (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	½- 0	Dark greyish brown 10 YR 4/2		Very dark brown 10 YR 2/2			
Ahe	0 - 3½	Dark brown 10 YR 4/3		Dark brown 10 YR 3/3			
AB	3½- 8	Brown 10 YR 5/3		Dark brown 10 YR 4/3			
Bt ₁	8 -11	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4			
Bt ₂	11 -14	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4			
BC	14 -17	Light brownish grey 10 YR 6/2		Dark brown 10 YR 3/3			
C ₁	17 -25	Greyish brown 2.5 Y 5/2		Very dark grey-brown 2.5 Y 3/2			
C ₂	25 -33	Greyish brown 2.5 Y 5/2		Dark grey brown 2.5 Y 4/2			
C ₃	33 -43	Greyish brown 2.5 Y 5/2		Dark grey brown 2.5 Y 4/2			

Topography -- gently rolling with slope of about 5 per cent; sample was taken almost at crown of hump.

* Munsell colors

TABLE V. PROFILE DESCRIPTION OF SITE 5

Legal Location	Depth (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	1 - 0	Dark greyish brown 10 YR 3/2		Very dark brown 10 YR 2/2			
Ahe	0 - 5	Light brownish grey 10 YR 6/2		Dark brown 7.5 YR 3/2		SICL	Fine granular, friable
AB	5 - 8	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4		SICL	Sub-angular blocky, firm
Bt ₁	8 - 13	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4		SIC	Medium sub-angular blocky, firm
Bt ₂	13 - 19	Pale brown 10 YR 6/3		Dark yellowish brown 10 YR 4/4		SIC	Coarse sub-angular blocky, weak prismatic, firm
Bt ₃	19 - 24	Pale brown 10 YR 6/3		Olive brown 2.5 Y 4/4		SIC	Coarse sub-angular blocky, weak prismatic, firm
BC	24 - 29	Pale brown 10 YR 6/3		Dark grey brown 2.5 Y 4/2		SICL	Coarse sub-angular blocky to massive, firm
C ₁	29 - 34	Light brownish grey 2.5 Y 6/2		Very dark grey brown 2.5 Y 3/2		SICL	Medium blocky, firm to friable
C ₂	34 - 40	Light brownish grey 2.5 Y 6/2		Very dark grey brown 2.5 Y 3/2		SIC	Medium to coarse blocky, firm to friable
C ₃	40 - 48	Light brownish grey 2.5 Y 6/2		Very dark grey brown 2.5 Y 3/2		SIC	Medium to coarse blocky, firm to friable
Topography -- gently rolling with slope of about 6 per cent; sample was taken one-half way down slope from crown of hump.							

* Munsell colors

TABLE VI. PROFILE DESCRIPTION OF SITE 6

Legal Location	Depth (in.)	Horizon (in.)	Color*	Dry	Color*	Moist	Texture	Structure and Consistency
L - H	2 - 0	Very dark grey 5 YR 3/1	Very dark brown 10 YR 2/2	Brown 10 YR 5/3	Sil	Very fine platy, friable		
Ae ₁	0 - 2	Very pale brown 10 YR 7/3	Very pale brown 10 YR 7/3	Brown 10 YR 5/3	Sil	Coarse platy, friable		
Ae ₂	2 - 4½	Very pale brown 10 YR 7/3	Very pale brown 10 YR 7/3	Dark brown 10 YR 4/3	SicL	Medium sub-angular blocky with grey coatings, firm to friable		
AB	4½ - 5½	Very pale brown 10 YR 7/3	Pale brown 10 YR 6/3	Dark yellow brown 10 YR 4/4	SicL	Sub-angular blocky, firm		
Bt ₁	5½ - 12½	Pale brown 10 YR 6/3	Pale brown 10 YR 6/3	Dark yellow brown 10 YR 4/4	SicL	Sub-angular blocky, firm		
Bt ₂	12½ - 15½	Pale brown 10 YR 6/3	Pale brown 10 YR 6/3	Dark yellow brown 10 YR 4/4	SicL	Sub-angular blocky, firm		
BC	15½ - 19½	Pale brown 10 YR 6/3	Pale brown 10 YR 6/3	Dark yellow brown 10 YR 4/4	SicL	Fine blocky, firm		
C ₁	19½ - 23½	Light brownish grey 2.5 Y 6/2		Dark yellow brown 10 YR 4/4	SicL - Sic	Fine sub-angular blocky, firm to friable		
C ₂	23½ - 25½	Light olive 5 Y 6/2		Dark grey brown 2.5 Y 4/2	Sic	Fine sub-angular blocky, slight laminar cleavage, firm		
C ₃	25½ - 37½	Light olive 5 Y 6/2		Dark grey brown 2.5 Y 4/2	Sic	Laminar cleavage, firm to friable		
C ₄	37½ - 44½	Light olive 5 Y 6/2		Dark grey brown 2.5 Y 4/2	Sic	Massive, tending toward lam- inar cleavage, firm to friable		
						Topography -- gently rolling with slope of 7 to 8 per cent; sample was taken about one-half way down from crown.		

* Munsell colors

The soils were washed during filtration with normal ammonium chloride to facilitate the removal of gypsum.

Bulk Density and Hygroscopic Moisture: Bulk density was determined on the cores collected during field sampling.

Hygroscopic moisture was determined by drying samples for 16 hours at 105°C.

Chemical Analyses

pH Measurements: pH was determined on a saturated soil paste as outlined by Doughty (21) using the Bach-Simson Radiometer pH meter.

Determination of Total Nitrogen: Nitrogen was determined by the Kjeldahl - Wilfarth - Gunning method (1). The catalyst used was HgO (0.41 g.), CuSO₄ (0.08 g.), and K₂SO₄ (9.9 g.) packaged in a polyethylene bag and sold commercially as Kel-pak*. The ammonia was collected in a 4 per cent H₃BO₃ solution as suggested by Meeker and Wagner (46) and titrated against standardized H₂SO₄.

Organic Carbon: Organic carbon content was determined by measuring the amount of total carbon evolved as CO₂ by the dry combustion method, as outlined in the A.O.A.C. manual (1).

* D-C Tab No. 1, Digestion Catalyst Powders, Harshaw Chemical Co., Cleveland 6, Ohio, U.S.A.

Calcium Carbonate Equivalent: Carbonates were determined by the modified A.O.A.C. (1) procedure for determining carbonate carbon. CO_2 is evolved by treating the soil with H_2SO_4 and FeSO_4 . The CO_2 is absorbed in ascarite or caroscite and weighed.

Free Iron Oxide: Mackenzie's method (42, 47) was used to determine free iron oxide, with the modification of adding dry $\text{Na}_2\text{S}_2\text{O}_4$ to the suspension of soil and water. The modification prevents the autodecomposition of the salt prior to its addition to the soil.

Exchangeable Cations and Exchange Capacity: Exchangeable cations were extracted from the samples with normal ammonium acetate adjusted to pH 7 as outlined in the A.O.A.C. methods of analyses (1). Exchangeable potassium, sodium, calcium, and magnesium were determined with the model DU Beckman Flame Spectrophotometer.

Exchangeable acidity was determined by 0.5 N barium acetate adjusted to pH 7 and titrated with standardized NaOH (12).

The cation exchange capacity was determined by the extraction of adsorbed ammonia with normal sodium chloride and distillation of the extract was carried out according to the magnesium oxide method for ammoniacal nitrogen (1).

Mineralogical Analyses

Clay Analyses: Identification of the clay minerals present in the coarse and fine clay fractions were made using X-ray diffraction methods. The X-ray unit was a Norelco X-ray diffractometer with high angle goniometer. The radiation was CuK α using a nickel filter.

The initial treatment prior to X-radiation consisted of removing carbonates, soluble salts, and organic matter of the samples by the method outlined by Jackson *et al.* (30). Dispersion of clays and subsequent separation of clay from sand and silt followed by separation of the clay into fine and coarse fractions was carried out by the method used by Pawluk¹. The method consists essentially of dispersing the clays by adjusting the suspension to pH 8.0 with sodium hydroxide. The suspension was allowed to equilibrate overnight and the pH was readjusted to 8.0. The separation of clay from silt and sand fractions was accomplished simply by repeated decantation of the upper 8 cm. of suspension after standing for 6 hours and 8 minutes. The coarse (2 - 0.2 u) and fine (< 0.2 u) clay fractions were separated by centrifugation of the clay suspensions for 1 hour and 6 minutes at 1,800 r.p.m. with an International No. 2 Electrifuge. Settling times and centrifuge speeds were calculated by the use of Stokes Law adopted for centrifugation by Baver (19).

¹ Personal communication

The clay fractions were flocculated with calcium by adding calcium chloride followed by washing with distilled water to remove chlorides. The clay suspensions were mounted on glass slides according to the method of Kittrick (35). Essentially this entailed taking a few drops of the clay suspension, placing it on the slide and allowing the clay to dry by standing overnight in petri dishes covered with a large ribbed cover glass. The ethylene glycol treatment of the air-dried mounted suspensions was carried out by placing prepared slides in a saturated atmosphere of ethylene glycol in a vacuum dessicator. Duplicate slides of the samples were heat treated at 550°C. for 2 hours and stored in a dessicator.

Cation exchange capacity of the two clay fractions were determined according to a procedure similar to that for the exchange capacity of the soil, except that centrifugation was used to separate the suspension and solution.

Light Mineral Analyses: Approximately 400 - 600 g. of soil were wet sieved. The 0.10 to 0.05 millimetre fraction which remained between a 300 mesh and a 200 mesh sieve was saved for analyses. This fraction was washed free of clay and iron stains by treating with boiling water and $\text{Na}_2\text{S}_2\text{O}_4$ as for the previously mentioned free iron oxide determination. The light mineral fraction was then obtained by heavy liquid separation retaining the < 2.70 specific gravity portion. The heavy liquid used was a mixture of tetrabromoethane and

nitrobenzene, yielding a liquid of specific gravity of 2.70. X-ray analyses were carried out to identify the mineral species present in this fraction.

Chemical composition of the light mineral fraction was determined by the hydrofluoric and sulfuric acid method outlined by Atkinson et al. (2). Elemental analyses were determined on the decomposed samples. Calcium was determined by the complexometric titration with E.D.T.A. as outlined by Bentley and Pawluk (a modification of the Cheng and Bray (17) technique). Sodium and potassium were determined by flame photometry employing the Beckman Model DU Flame Spectrophotometer. Iron was determined by the colorimetric technique mentioned previously. Aluminum was determined by gravimetric precipitation according to the method outlined by Koltoff and Sandell (36).

IV. RESULTS AND DISCUSSION

Physical, chemical, and mineralogical analyses were conducted in order to characterize the soil profiles under study and confirm their field identification. The results of these analyses appear in Table VII (a-f), pages 47 to 52; Table VIII (a-f), pages 53 to 58; Table IX, page 59; and Table X, page 60. In Table VII (a-f) the physical determination of mechanical analysis, bulk density, and hygroscopic moisture are reported. The chemical analyses are presented in Table VIII (a-f). The percentage of the various exchangeable cations are based on their sums for the individual horizons. Both the determined and summed cation exchange capacities are given. Calcium carbonate equivalents are reported for horizons which are alkaline in reaction. Organic carbon, nitrogen, calculated C:N, and pH for each horizon are tabulated. Free iron oxides are given for representative horizons. In Table IX the various clay minerals and their relative amounts are tabulated for three representative horizons of each site. In Table X a quantitative estimate of the light minerals (sp. gr. < 2.70) is reported, along with a calculated weathering ratio of feldspars to quartz. A number of figures showing clay distribution of the various profiles and X-ray diffraction patterns are also presented.

TABLE VII(a). PHYSICAL ANALYSES OF SITE 1

Horizon	Depth (inches)	Mechanical Analysis						Bulk Density g/c.c.	Hygroscopic H ₂ O %
		Sand %	Silt %	Clay %	C.C. 1 %	F.C. 2 %			
L-H	1- 0							5.90	
Ahe	0- 2	7	60	33	32	1	1.10		2.38
AB	2- 4	2	48	50	27	23	1.15		2.43
Bt ₁	4- 7	2	58	40	36	4	1.34		3.84
Bt ₂	7-12	1	47	52	44	8	1.50		4.05
BC	12-15	1	54	45	39	6	1.50		3.53
C ₁	15-19	1	65	34	34	T*	1.46		2.60
C ₂	19-25	1	65	34	34	T*	1.45		2.44
C ₃	25-35	1	64	35	35	T*	1.66		2.20

1 2.0-0.2 microns

2 less than 0.2 microns

* less than 1%

TABLE VII(b). PHYSICAL ANALYSES OF SITE 2

Horizon	Depth (inches)	Mechanical Analysis						Hygroscopic H ₂ O %
		Sand %	Silt %	Clay %	C.C. %	F.C. %	Bulk Density g/c.c.	
L-H	1- 0							7.47
Ahe	0- 3	3	61	36	27	9	0.65	2.68
AB	3- 7	1	50	49	29	20	0.97	2.71
Bt ₁	7-13	T*	48	52	26	26	1.48	3.37
Bt ₂	13-17	T*	56	44	20	24	1.41	3.32
BC	17-19	1	47	52	27	25		3.12
C ₁	19-25	2	52	46	33	13	1.36	2.24
C ₂	25-31	3	59	38	25	13	1.29	2.31
C ₃	31-41	2	52	46	34	12	1.34	1.87

1 2.0-0.2 microns

2 less than 0.2 microns

* less than 1%

TABLE VII(C). PHYSICAL ANALYSES OF SITE 3

Horizon	Depth (inches)	Mechanical Analysis					Hygroscopic H ₂ O %
		Sand %	Silt %	Clay %	C.C. 1 %	F.C. 2 %	
L-H	2-0						9.00
Ah	0-3	5	79	16	15	1	0.68
Ahe	3-6	4	60	36	18	18	3.75
BA	6-8	3	48	49	22	27	3.00
Bt ₁	8-13	5	49	46	14	32	4.14
Bt ₂	13-17	5	30	65	32	32	4.62
BC	17-21	4	27	69	38	31	4.62
C ₁	21-25	1	46	53	26	27	4.62
C ₂	25-29	1	48	51	31	20	3.34
C ₃	29-36	1	55	44	26	18	3.19
C ₄	36-49	1	52	47	31	16	3.18

¹ 2.0-0.2 microns² less than 0.2 microns

TABLE VII(d). PHYSICAL ANALYSES OF SITE 4

Horizon	Depth (inches)	Mechanical Analysis					Bulk Density g./c.c.	Hygroscopic H ₂ O %
		Sand %	Silt %	Clay %	C.C. 1 %	F.C. 2 %		
L-H	1- 0						4.67	
Ahe	0- 3½	2	67	31	28	3	0.66	6.45
AB	3½- 8	1	66	33	17	16	1.18	4.12
Bt ₁	8-11	1	59	40	17	23	1.28	4.64
Bt ₂	11-14	1	52	47	16	31	1.28	4.90
BC	14-17	1	53	46	16	30	1.31	3.91
C ₁	17-25	1	60	39	22	17	1.34	4.20
C ₂	25-33	1	60	39	28	11	1.31	2.48
C ₃	33-43	2	65	33	24	9	1.34	3.98

1 2.0-0.2 microns

2 less than 0.2 microns

TABLE VII(e). PHYSICAL ANALYSES OF SITE 5

Horizon	Depth (inches)	Mechanical Analysis						Hygroscopic H ₂ O %
		Sand %	Silt %	Clay %	C.C. 1 %	F.C. 2 %	Bulk Density g/c.c.	
L-H	1- 0						9.44	
Ahe	0- 5	8	62	31	19	12	1.03	2.22
AB	5- 8	5	58	37	16	21	1.41	2.41
Bt ₁	8-13	3	54	42	18	25	1.33	3.73
Bt ₂	13-19	3	53	44	18	26	1.47	3.15
Bt ₃	19-24	2	43	55	29	26	1.62	2.93
BC	24-29	1	63	36	24	12	1.61	2.76
C ₁	29-34	T*	68	32	14	18	1.59	2.71
C ₂	34-40	1	52	47	35	12	1.58	2.74
C ₃	40-48	T*	52	48	35	13	1.39	4.76

1 2.0-0.2 microns

2 less than 0.2 microns

TABLE VII (F). PHYSICAL ANALYSES OF SITE 6

Horizon	Depth (inches)	Mechanical Analysis					Bulk Density g/c.c.	Hygroscopic $H_2O\ %$
		Sand %	Silt %	Clay %	C.C. %	F.C. %		
L-H	2 - 0						7.64	
Ae1	0 - 2	17	67	16	16	T*	1.32	1.60
Ae2	2 - 4½	11	65	24	12	12	1.50	1.83
AB	4½ - 5½	9	62	29	16	13	1.48	1.96
Bt ₁	5½ - 12½	11	55	34	14	20	1.47	2.72
Bt ₂	12½ - 15½	11	53	36	14	22	1.29	3.20
BC	15½ - 19½	11	54	35	13	22	1.29	3.16
C ₁	19½ - 23½	7	53	40	22	18	1.37	2.74
C ₂	23½ - 25½	1	54	45	33	18	1.55	2.40
C ₃	25½ - 37½	T*	48	52	38	14	1.56	3.10
C ₄	37½ - 49½	T*	49	51	37	14	1.60	2.90

1 2.0-0.2 microns

2 less than 0.2 microns

* less than 1%

TABLE VIII(a). SOME CHEMICAL ANALYSES OF SITE 1

Horizon	% of Total C.E.C.*				Total C.E.C. me./100 g.		Sum of Ex.Cations	Deter- mined	CaCO ₃ %	Organic C %	N %	C:N	pH	Fe ₂ O ₃ %
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺									
L-H	10.6	67.9	13.5	0.9	7.1	57.7	62.8	--	19.31	1.140	17	6.4	--	
Ahe	14.5	71.0	9.1	0.6	4.8	31.0	24.8	--	4.05	0.308	13	5.6	0.277	
AB	6.4	75.8	14.7	0.8	2.3	26.4	21.3	--	1.40	0.129	11	6.2	--	
Bt ₁	5.5	74.9	17.3	0.6	1.7	34.7	28.7	--	1.25	0.103	12	5.3	--	
Bt ₂	10.0	72.6	15.9	0.5	1.0	37.2	29.8	--	2.97	0.085	35	5.3	0.526	53
BC	5.7	79.1	13.6	0.5	1.1	36.7	26.4	--	2.43	0.106	23	5.8	--	
C ₁	--	86.4	11.8	0.6	1.2	33.0	20.0	4.60	2.84	0.128	22	8.2	--	
C ₂	--	91.9	7.0	0.4	0.7	54.4	17.8	18.66	--	0.107	--	8.2	0.281	
C ₃	--	93.3	5.7	0.3	0.7	42.0	17.2	17.04	--	0.091	--	8.2	--	

* Based on sum of exchangeable cations

TABLE VIII(b). SOME CHEMICAL ANALYSES OF SITE 2

Horizon	% of Total C.E.C.*				Total C.E.C.		Organic C %	N %	C:N	pH	Fe ₂ O ₃ %
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Sum of Ex. Cations	Deter-mined	CaCO ₃ %			
L-H	7.0	67.7	18.6	0.7	6.0	58.2	74.6	--	27.97	1.728	16 7.2 --
Ahe	2.1	85.9	8.2	0.3	3.5	29.1	25.6	--	3.43	0.244	14 7.2 0.314
AB	6.3	76.7	14.1	0.5	2.4	20.6	20.8	--	1.28	0.109	12 6.6 --
Bt ₁	5.1	73.5	19.6	0.4	1.4	27.5	24.4	--	0.88	0.096	9 6.0 --
Bt ₂	4.0	75.3	18.7	0.7	1.3	30.0	24.5	--	0.80	0.088	9 6.5 0.634
BC	1.3	78.7	18.4	0.3	1.3	30.5	22.4	0.18	0.92	0.089	10 7.1 --
C ₁	--	90.3	8.8	0.2	0.7	55.9	16.6	16.76	1.01	0.093	11 8.0 --
C ₂	--	87.3	11.6	0.4	0.7	56.1	14.0	24.29	0.91	0.096	10 8.0 0.277
C ₃	--	81.8	17.0	0.4	0.8	49.5	15.1	25.28	0.86	0.086	10 8.0 --

* Based on sum of exchangeable cations

TABLE VIII(c). SOME CHEMICAL ANALYSES OF SITE 3

Horizon	% of Total C.E.C.*				Total C.E.C.		Organic C %	N % C:N	pH	Fe ₂ O ₃ %
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Sum of Ex.Cations	Deter- mined			
	me./100 g.	me./100 g.	me./100 g.	me./100 g.	me./100 g.	me./100 g.	me./100 g.			
L-H	13.3	72.8	11.5	0.4	2.0	108.6	89.7	--	11.71	1.441
Ah	15.2	64.3	17.0	0.9	2.6	34.2	33.0	--	3.45	0.284
Ahe	18.4	61.1	17.6	0.7	2.2	27.8	24.7	--	1.70	0.145
BA	19.9	55.6	21.8	0.8	1.9	26.1	28.0	--	0.97	0.083
Bt ₁	20.1	54.2	23.5	0.6	1.6	32.3	29.0	--	0.91	0.063
Bt ₂	18.1	55.0	24.5	0.9	1.5	32.7	30.3	--	0.89	0.059
BC	12.8	59.8	25.0	0.6	1.8	32.8	29.5	--	0.71	0.057
C ₁	--	71.5	25.7	1.1	1.7	35.0	28.8	0.55	1.29	0.075
C ₂	--	80.9	17.1	0.8	1.2	51.3	26.3	3.35	1.21	0.088
C ₃	--	80.7	17.5	0.8	1.0	50.2	24.3	3.34	1.47	0.091
C ₄	--	80.5	17.6	0.8	1.1	59.0	23.0	3.71	1.47	0.099

* Based on sum of exchangeable cations

TABLE VIII(d). SOME CHEMICAL ANALYSES OF SITE 4

Horizon	% of Total C.E.C.*				Total C.E.C. me./100 g.		Sum of Ex.Cations	Deter- mined	CaCO ₃ %	C %	N %	C:N	pH	Fe ₂ O ₃ %
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺									
L-H	3.1	84.2	7.1	0.8	4.8		58.9	47.4	--	10.80	0.723	15	6.8	--
Ahe	6.5	77.6	13.2	0.5	2.2		37.1	32.1	--	4.18	0.278	15	6.1	0.389
AB	11.5	72.5	13.9	0.7	1.4		28.7	29.5	--	1.76	0.133	14	5.2	--
Bt ₁	9.8	74.0	14.3	0.6	1.3		33.8	27.2	--	1.37	0.090	15	5.0	--
Bt ₂	10.8	73.8	13.3	0.6	1.5		33.2	28.8	--	1.25	0.085	16	4.8	0.547
BC	10.3	74.9	12.7	0.6	1.5		33.1	27.3	--	1.17	0.100	12	5.2	--
C ₁	--	91.2	7.8	0.4	0.6		53.7	20.8	10.9	1.45	0.115	13	7.6	--
C ₂	--	91.5	7.5	0.4	0.6		53.5	17.9	14.1	1.45	0.113	13	7.7	0.276
C ₃	--	91.4	7.3	0.6	0.7		54.7	14.9	10.8	1.06	0.088	12	7.5	--

* Based on sum of exchangeable cations

TABLE VIII(e). SOME CHEMICAL ANALYSES OF SITE 5

Horizon	% of Total C.E.C.*				Total C.E.C. me./100 g.		Organic C %	N % C:N	pH	Fe ₂ O ₃ %
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Sum of Ex.Cations	Deter- mined			
L-H	8.6	66.0	19.1	0.5	5.8	65.5	77.1	--	32.29	1.726
Ahe	8.0	76.5	10.7	0.4	4.4	27.2	20.4	--	3.00	0.214
AB	8.6	72.2	16.2	0.4	2.6	22.2	20.0	--	1.35	0.124
Bt ₁	8.0	71.2	17.2	0.4	3.2	25.0	21.7	--	1.01	0.106
Bt ₂	8.9	68.8	19.2	0.4	2.7	22.4	21.7	--	1.01	0.086
Bt ₃	8.6	68.5	19.7	0.8	2.4	25.4	22.4	--	0.81	0.079
BC	7.5	72.2	17.8	0.8	1.7	24.1	21.6	--	0.80	0.082
C ₁	--	88.5	10.3	0.4	0.8	50.3	19.0	7.67	1.07	0.101
C ₂	--	89.4	9.7	0.4	0.5	55.7	19.1	14.92	1.12	0.095
C ₃	--	77.2	21.5	0.4	0.9	46.4	33.9	1.30	1.06	0.082

* Based on sum of exchangeable cations

TABLE VIII(F). SOME CHEMICAL ANALYSES OF SITE 6

Horizon	% of Total C.E.C.*				Total C.E.C.		Organic			Fe ₂ O ₃ %		
	H ⁺	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Sum of Ex.Cations	Deter- mined	CaCO ₃ %	C %	N %		
L-H	2.1	76.9	17.5	0.3	3.2	69.3	84.3	--	22.70	1.404	16	6.7
Ae ₁	9.9	70.3	16.7	1.0	2.1	19.2	14.6	--	1.69	0.120	14	6.4
Ae ₂	10.3	63.0	23.9	0.6	2.2	18.4	14.8	--	0.92	0.080	12	5.9
AB	11.0	64.6	21.9	0.6	1.9	15.5	15.5	--	0.79	0.066	11	5.4
Bt ₁	8.0	59.5	29.5	0.8	2.2	23.7	18.7	--	0.61	0.066	9	5.8
Bt ₂	6.0	61.1	30.6	0.8	1.5	26.8	22.1	--	0.56	0.059	9	5.7
BC	--	72.5	25.7	0.6	1.2	34.2	21.5	--	0.57	0.062	10	7.0
C ₁	--	79.0	19.5	0.9	0.6	62.0	17.3	10.3	0.65	0.066	9	7.8
C ₂	--	76.4	22.0	1.1	0.5	60.9	17.2	21.1	0.79	0.079	10	8.0
C ₃	--	75.1	22.7	1.6	0.6	62.6	18.8	15.7	0.73	0.065	12	8.0
C ₄	--	75.3	22.3	1.8	0.6	62.7	18.5	13.6	0.73	0.087	8	8.0

* Based on sum of exchangeable cations

TABLE IX. CLAY MINERAL DISTRIBUTION IN SOILS UNDER STUDY

Site and Horizon	Mont- morillonite* 2-0.2 0.2 microns	Illite* 2-0.2 0.2 microns	Kaolinite* 2-0.2 0.2 microns	Chlorite*			Mixed Layers*			Quartz*			C.E.C.**
				2.0.2 0.2 microns			2-0.2 0.2 microns			2-0.2 0.2 microns			2-0.2 0.2
				2	0	2	2	0	2	2	0	2	0.2
1	Ahe	2	4	4	4	3	4	2	1	2	1	4-3	2
	Bt ₂	2	4-5	4	3	3	3	3	3	3	3	3	18.0
	C ₂	2	5	4	1	3	1	3	1	3	1	18.4	85.0
2	Ah	2-3	3	4	3	3	2-3	1	1	4-5	3	2-3	14.1
	Bt ₂	2-3	4	4-3	3	3	3	2	1	3	3	3	17.6
	C ₂	3-2	4-5	4-3	3	3	3	2	1	1	3	3	14.0
3	Ah	3	4	4	3	4	3	1	1	3	2	3	2-3
	Bt ₂	3-4	4-5	4	3-2	4	3	2	1	2	3	3	2-3
	C ₂	4	4-5	3	3	3	3	1	1	1	2	2	2-3
4	Ahe	1	5-4	4	3	3	3	1	2-3	2	2	3	16.5
	Bt ₂	3	5-4	4	3	2	3	3	2-3	2	2	3	19.2
	C ₂	3	4-5	4	3	2	3	2-3	1	2	1	3	16.4
5	Ahe	2	4-5	4	3	3	3	2	1	1	1	3	18.7
	Bt ₂	3	4-5	4-3	3	3	3	2	1	1	1	3	18.5
	C ₂	3	4-5	4-3	3	3	3	2	1	1	1	3	18.0
6	Ae ₂	3	4-5	3	3	3	3	2-3	1	2	1	3	21.6
	Bt ₂	3	5	3	3	3	3	2-3	1	2	1	3	24.1
	C ₂	4-3	5	4-3	3	3	3	2-3	1	1	1	3	28.1

* Expressed as relative quantities in the following serial progression:

1. None
2. Trace 0-10%
3. Minor 10-35%
4. Major 35-65%
5. Dominant 65-100%

** Milliequivalents per 100 grams

TABLE X. QUANTITATIVE ESTIMATES OF LIGHT MINERALS (sp.gr. less than 2.70)

Site and Horizon	Elemental Analyses						K Feldspar %	Soda-Calcic Feldspar %	Quartz* %	<u>Feldspar</u> <u>Quartz</u> / <u>Quartz</u>
	K ₂ O %	Na ₂ O %	CaO %	Al ₂ O ₃ %	Fe ₂ O ₃ %	SiO ₂ * %				
1	Ahe	1.51	1.52	0.78	5.62	0.88	89.69	6	12	0.217
	Bt ₂	1.05	1.62	1.07	6.78	1.06	88.42	4	14	0.217
	C ₂	1.20	1.72	1.37	7.79	1.53	86.39	5	15	0.250
2	Ah	1.81	0.34	2.05	6.75	1.65	87.40	8	7	0.176
	Bt ₂	1.25	2.35	1.89	8.53	1.47	84.51	6	12	0.220
	C ₂	0.70	1.11	4.16	13.98	0.75	89.30	3	22	0.333
3	Ah	0.96	1.02	0.39	4.10	0.34	93.19	4	7	0.123
	Bt ₂	0.86	0.88	0.33	4.42	0.56	92.95	4	7	0.123
	C ₂	1.05	1.12	0.84	5.38	0.64	90.97	4	10	0.163
4	Ahe	3.10	0.71	2.45	16.73	2.74	74.27	17	13	0.430
	Bt ₂	0.60	0.84	0.63	4.57	0.74	92.62	3	7	0.111
	C ₂	1.19	1.24	2.23	8.53	2.25	84.56	6	15	0.266
5	Ahe	1.10	1.09	0.78	5.06	0.79	91.18	5	9	0.163
	Bt ₂	1.00	1.38	0.58	4.88	0.70	91.46	4	11	0.176
	C ₂	1.50	1.83	1.27	15.29	1.30	78.81	7	18	0.333
6	Ae ₂	0.96	1.03	0.36	4.68	0.61	92.36	4	7	0.124
	Bt ₂	0.90	1.06	0.30	3.68	0.60	93.46	4	8	0.136
	C ₂	1.52	2.52	1.23	8.79	2.27	83.67	7	21	0.389

* Determined by difference

Physical Analyses

Mechanical Analysis: Mechanical analysis provides the percentage distribution of the particles size (9). Fine clay is that size range consisting of < 0.2 microns and coarse clay the size range of 2 - 0.2 microns.

Table VII (a-f), pages 47 to 52, indicate that all of the soils were of a silty clay loam to silty clay with the exception of site 3 where the Bt_2 and BC were clay in texture and sites 3 and 6 where the A horizons were silt loam in texture. Total clay ranged from a minimum of 16 per cent to a maximum of 69 per cent.

There was great variability in the clay content of the various surface horizons ranging from 16 to 36 per cent. In all profiles the percentage of clay was greater in the B horizon than in the A horizon. Similarly, in all the profiles, with the exception of site 6, the clay content was higher in the B than in the C horizons. In site 6 the clay content increased with depth, which may be explained by its immediate association with clayey lacustrine soils found about one-eighth of a mile from this site. Stratification of the parent materials was evident from the variation of the clay content of the various sub-divisions of the C horizons.

Figures 2, 3, and 4 show the clay distribution at each site as a function of depth. From these figures it was evident that in each case there is a greater amount of fine clay and total clay in the B horizons, with the exception of

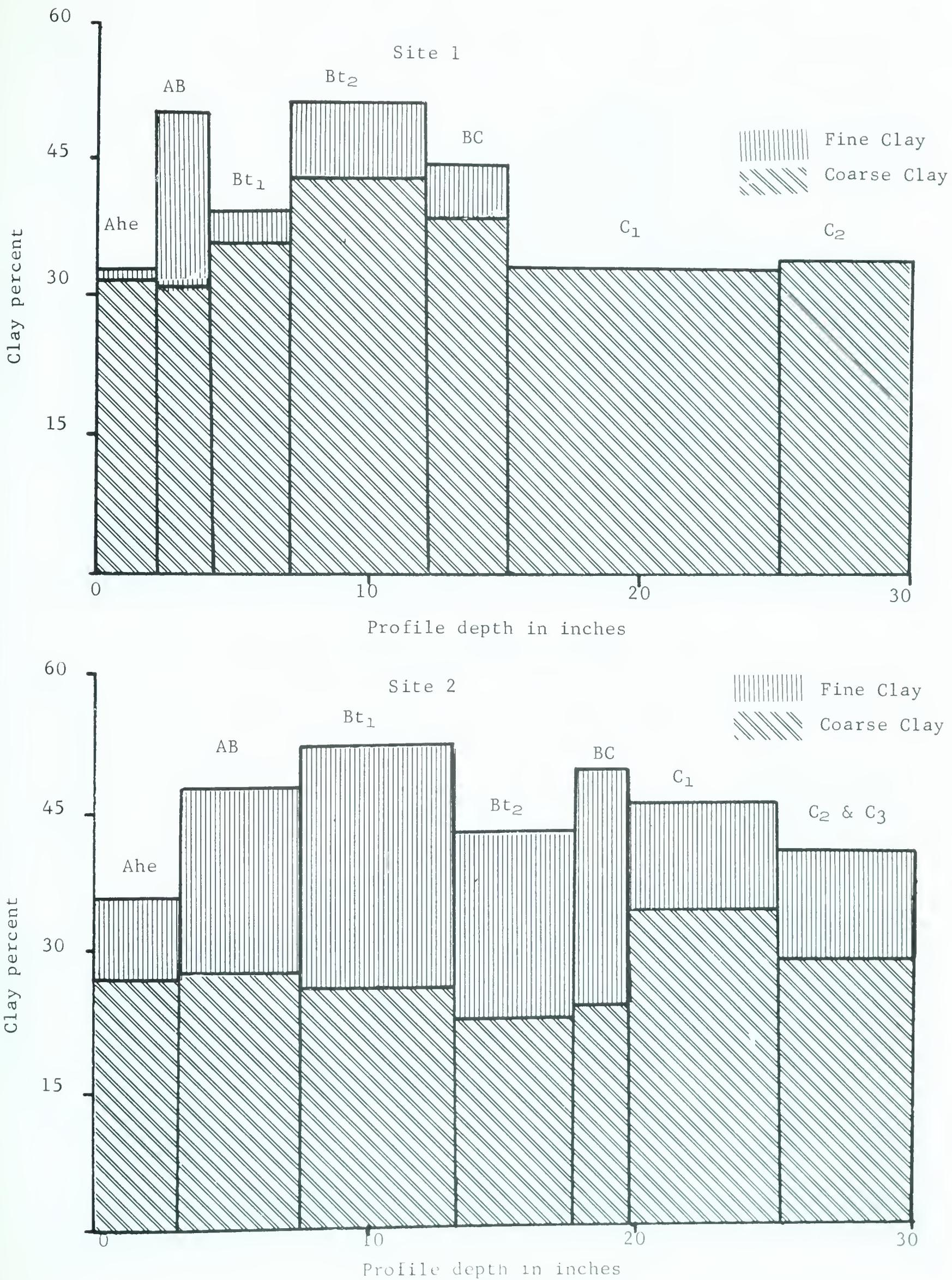
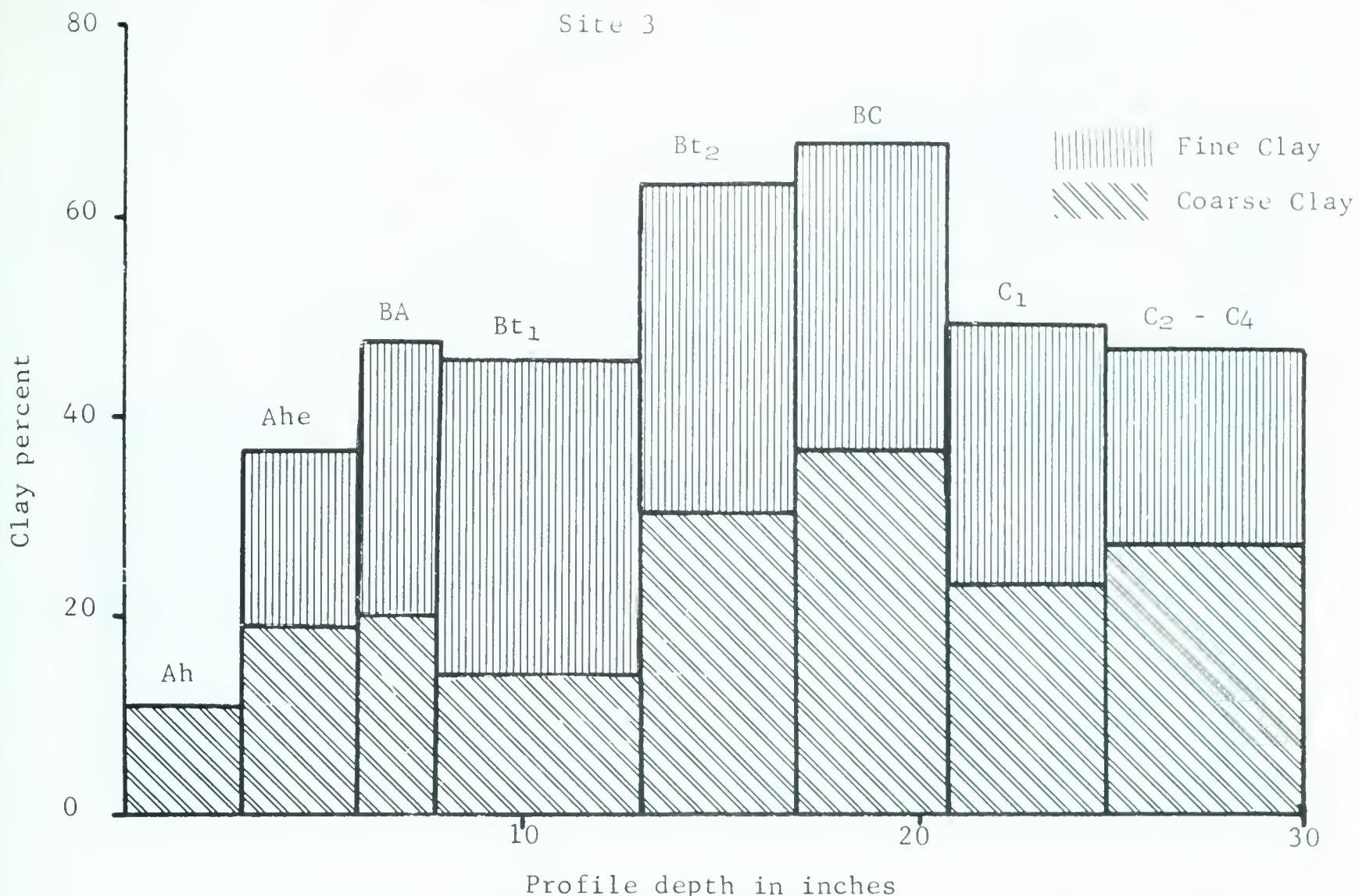


Figure 2. Clay distribution in soil profiles at Sites 1 and 2.

Site 3



Site 4

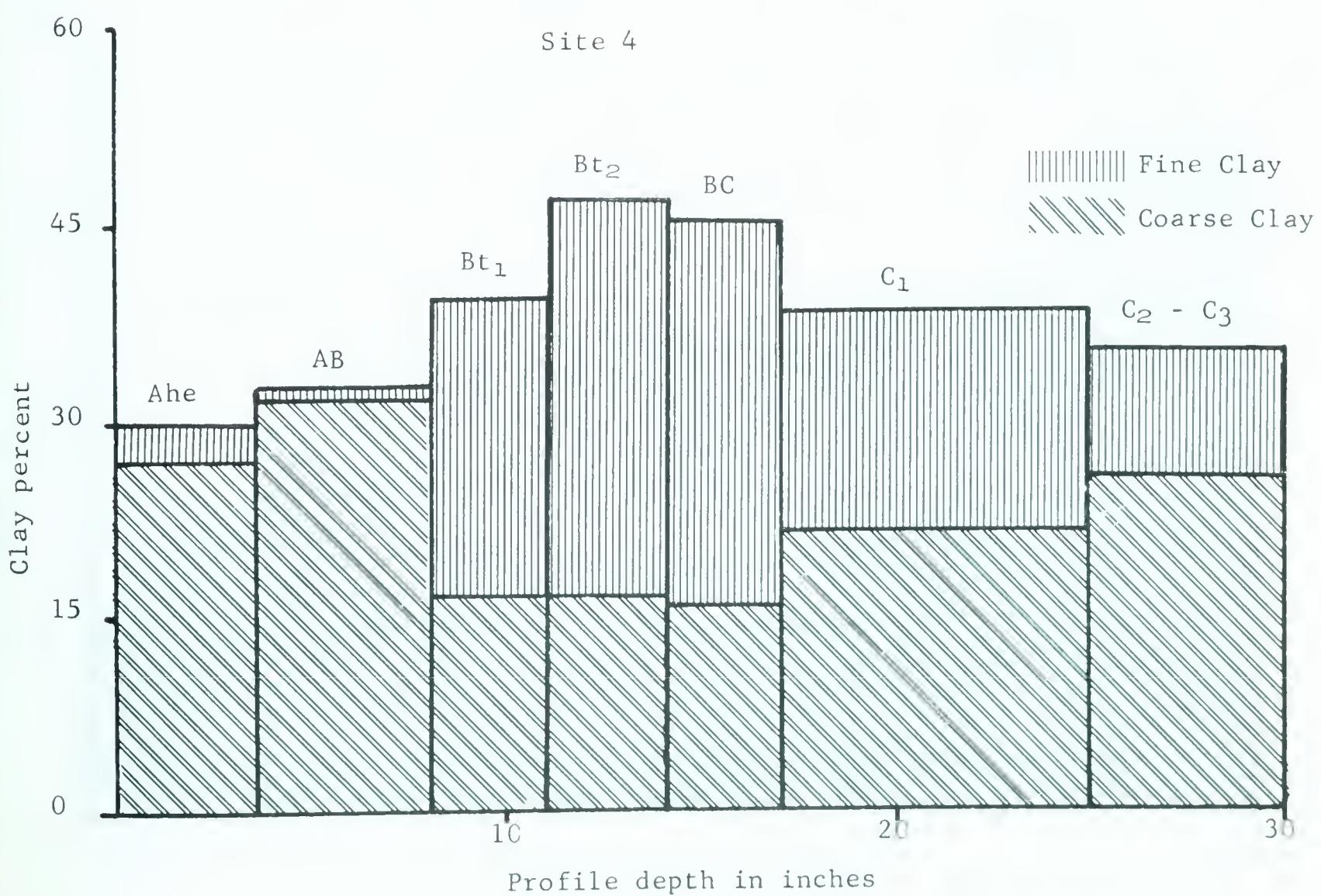


Figure 3. Clay distribution in soil profiles at Sites 3 and 4.



Figure 4. Clay distribution in soil profiles at Sites 5 and 6.

total clay at site 6. Generally the clay content, especially fine clay, was greatest in the lower Bt horizons.

The silt percentages for all sites, with the possible exception of site 6, decreased from the A to the B and/or BC horizons and increased in the lower portion of the profiles. The higher silt content in the A horizons suggested either a removal of the clay fraction or a weathering of the sand to the silt-size fraction or possibly both, since the A horizons have generally greater amounts of sand. If it was assumed that the differences in the distribution of size fractions within the profile were pedogenic, then the A horizons have a loss and the B horizons an accumulation of clay-size material. This phenomenon was especially true of the fine clay fraction. Similar results for Grey Wooded soils have been reported by Pawluk (58) and by the Research Council of Alberta, Soil Survey (53, 54).

Bulk Density: Bulk density determinations are given in Table VII (a-f) in g. per c.c. According to Buckman and Brady (14), bulk densities range from 1.00 to as high as 1.80 or 2.00 g. per c.c. These workers stated that there was a tendency for bulk density to become greater with depth. Surface soils are generally well granulated and contain organic matter both of which encourage a porous condition resulting in low bulk density values. Bulk densities become generally greater with depth caused by a decrease in organic

matter content and by the downward movement of clay, iron, and aluminum oxides giving more dense layers.

Bulk densities for these soils vary from 0.65 to 1.66 g. per c.c. Generally the bulk density values increased from a low value in the A horizons to a maximum in the B horizons. Large variations in values for the C horizons were evident. Since during clay migration the pores of the illuviated horizon become filled by clay, there was a tendency for greater values for bulk density in B horizons. In the C horizons (presumably parent materials) there should be little variation of bulk density. However, due to the stratification of these parent materials there was considerable variation in values reported. The low values of around 0.6 were attributed to the greater amounts of organic matter and better granulation than in the lower solum. Solov'yev (66) found similar trends and values for some Chernozem soils which were under the influence of forest vegetation. Barshad (6) utilized bulk density values for evaluation of profile development for some soils in California.

Hygroscopic Moisture: Most of the hygroscopic water in soil is associated with the organic and inorganic colloidal material. Ordinarily the greater the content of colloidal material in a soil, the higher is the content of hygroscopic water (40). The values determined in this study were found to be highest in the organic horizons. Lower in the solum, hygroscopic water generally increased with clay content and

therefore the values were higher in the B horizons than in either the A or the C horizons. In the C horizons hygroscopic water was present in rather small amounts due to the dessicating effects of calcium carbonate.

Chemical Analyses

Exchangeable Cations and Cation Exchange Capacity: Exchangeable cations in the soil were found to be composed largely of calcium in all horizons, which generally reached a minimum in the lower B (Table VIII (a-f), pages 53 to 58). The podzolic processes caused by forest vegetation have not been severe enough, in any of the profiles, to remove all the exchangeable calcium. There was a large increase in exchangeable calcium content in the lower horizons due to the presence of free calcium carbonate.

The percentage of exchangeable magnesium remained fairly constant or increased slightly with depth in the solum. Similarly, exchangeable sodium and potassium either remained fairly uniform or decreased slightly with depth.

Exchangeable hydrogen was considered to be a measure of the H ions displaced from the exchange complex as well as H ions released by the hydrolysis of exchangeable hydrated Al ions. Exchange hydrogen generally decreased with depth of the solum and also decreased with decreasing pH. The decrease in pH and proportional increase in exchangeable hydrogen indicated that the podzolization process was active.

Results found in this study were generally in accordance with those reported for Alberta Grey Wooded soils (53, 54, 58).

The total exchange capacity as determined by summation differed from that found by direct determination. The large differences between the total exchange capacity for the C horizons as determined by summation and distillation might be accounted for by the presence of free calcium carbonate that was dissolved by the leaching solution and was partially extracted with the exchangeable calcium. Kelly (34) previously had demonstrated that ammonium acetate solution dissolves calcium carbonate more readily than water. In other horizons the total exchange capacity found by ammonia distillation was consistently lower than that found by summation except where organic matter was present. Determination of total exchangeable cations in samples of high organic matter content tend to be greater than that by summation. The results were in agreement with other cation exchange data reported for Alberta soils (53, 59).

pH and Calcium Carbonate Equivalents: The pH of the soils studied ranged from 4.2 to 8.2 with the lowest pH measured in the lower B horizon and the highest in the C horizon where free calcium carbonate was present. The lowest pH values for the complete solum was reported at site 3 and consequently the calcium carbonate equivalent was lowest in this profile. The pH determinations were (with the exception

of site 3) quite uniform from site to site. Other workers (54, 58) reported that the lowest pH values were found immediately above the zone of calcium carbonate accumulation.

Organic Carbon, Nitrogen, and Carbon: Nitrogen Ratios: The C:N ratios ranged from 8 to 19 with the highest ratios determined in the surface horizons (Table VIII (a-f)). High ratios were expected in the L - H horizons since little decomposition of the organic materials had taken place. High ratios were not expected in sub-surface horizons because of the lack of undecomposed organic materials. It was felt that slightly higher ratios were obtained in the lower sola on account of the presence of unweathered dolomitic materials. Russell (62) suggested that a C:N ratio of 10 was characteristic of soils in the British Isles, while Buckman and Brady (14) suggested the C:N ratios of the furrow slice of arable soils commonly ranged from 8 to 15. The Canadian Classification (50) defined Chernozemic soils as having Ah or Aa horizons with a C:N ratio of 17 or less if virgin and usually do not exceed 13 if cultivated. Thus the soils under study fit the definition of a Chernozemic Ah since the C:N ratios of the A horizons ranged from 12 to 15. The results reported here were in agreement with those reported elsewhere (53, 54) for similar soils.

Free Iron Oxide: Extractable hydrous iron oxide data are tabulated in Table VIII (a-f). The determination was carried out only on representative A, B, and C master horizons. The

values determined are for oxides soluble in hot sodium hydro-sulfite solution. Extractable hydrous oxides in soil profiles usually represent the dissolution of inorganic soil mineral constituents and consequently reflect to some extent the degree of chemical weathering which has occurred. The data showed that maximum accumulation was evident in the B horizons. However in some C horizons (sites 2, 4, 5, and 6) the content of free iron oxides was less than that determined in the A horizons. In other studies (58) the content in the C horizon was generally greater than in the A. This may be the result of the presence of high quantities of free calcium carbonate in the parent materials.

Mineralogical Analyses

X-ray Analyses of Clays: Semi-quantitative estimates for clay mineral distribution were based upon cation exchange data, by comparison of peak intensities, as discussed by Weaver (77) and by comparison with standard X-ray diffraction patterns determined for Alberta clay minerals of known composition¹.

X-ray diffraction patterns for the fine and coarse clay fractions are shown in Figures 5 to 10 and 11 to 16. The relative amounts of the minerals present are reported in Table IX, page 59.

¹

Personal communication with Dr. S. Pawluk

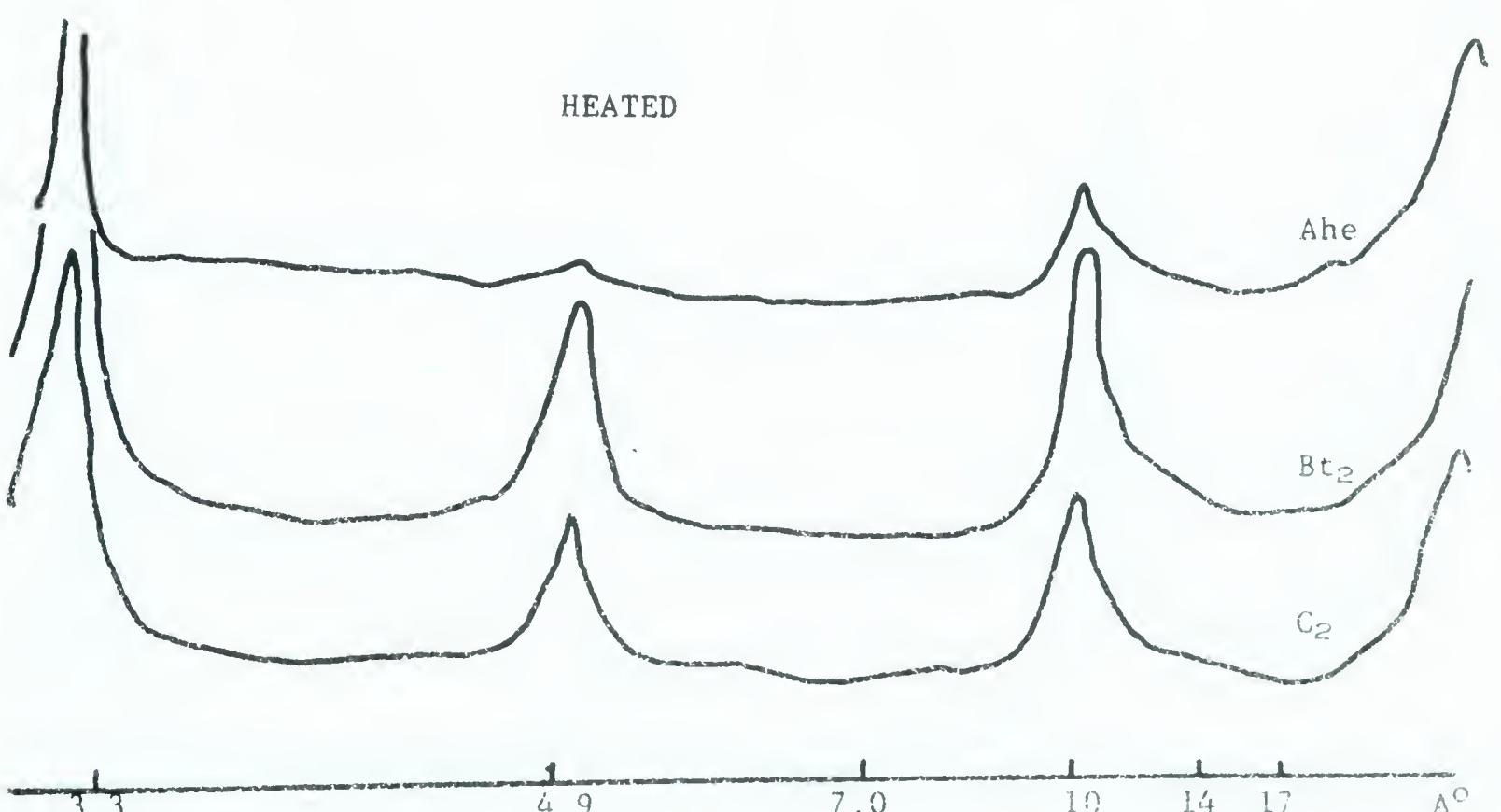
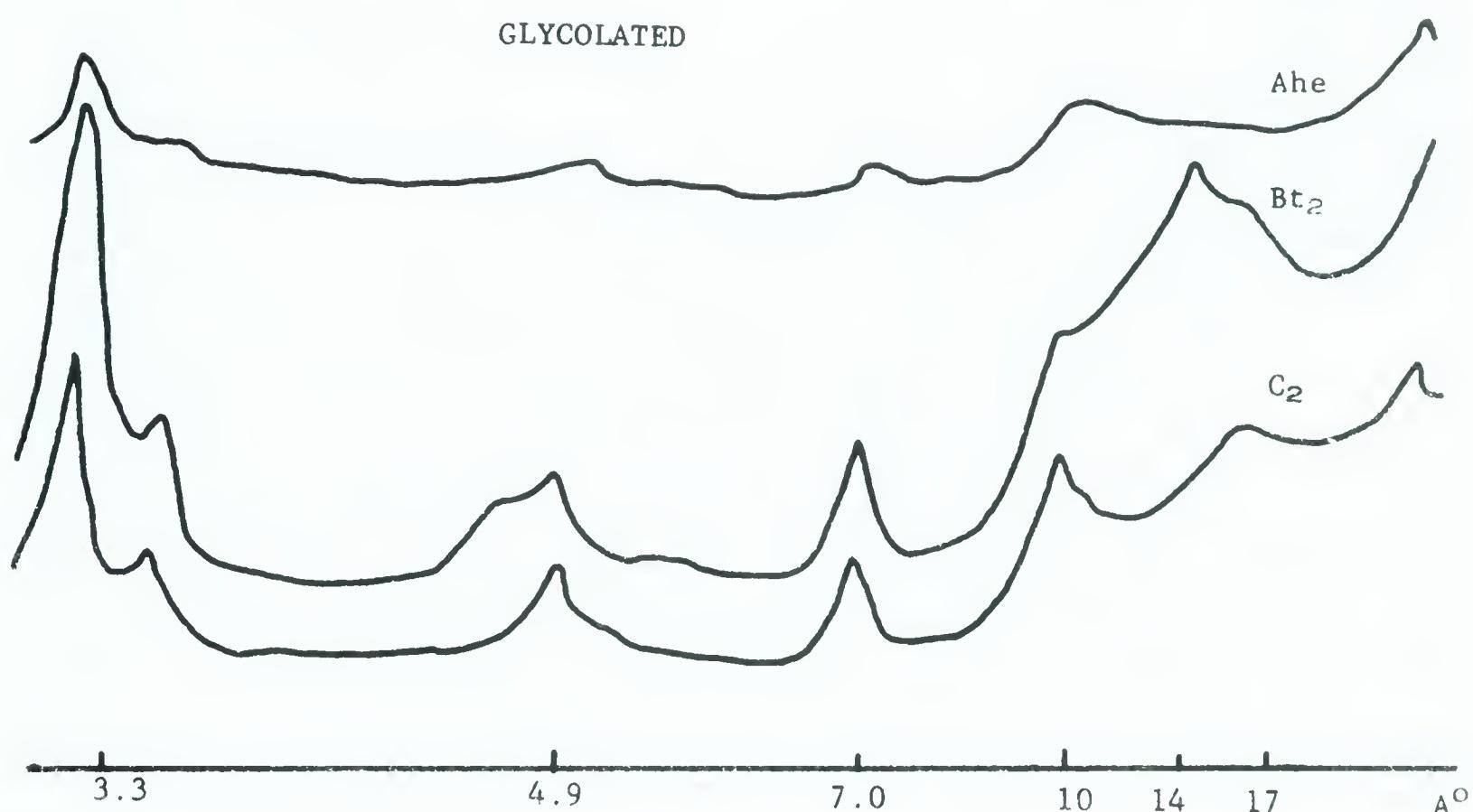


Figure 5. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 1.

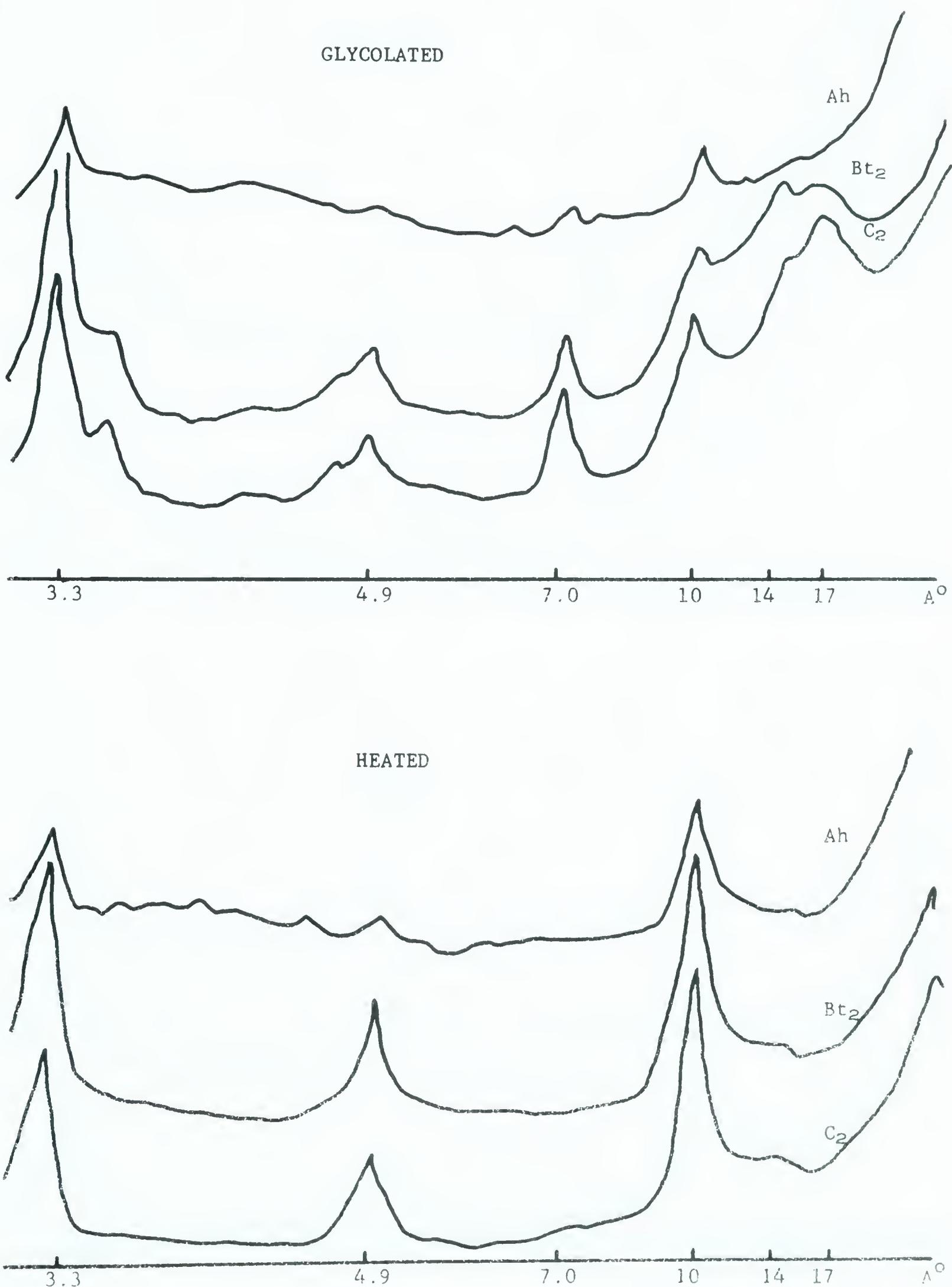


Figure 6. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 2.

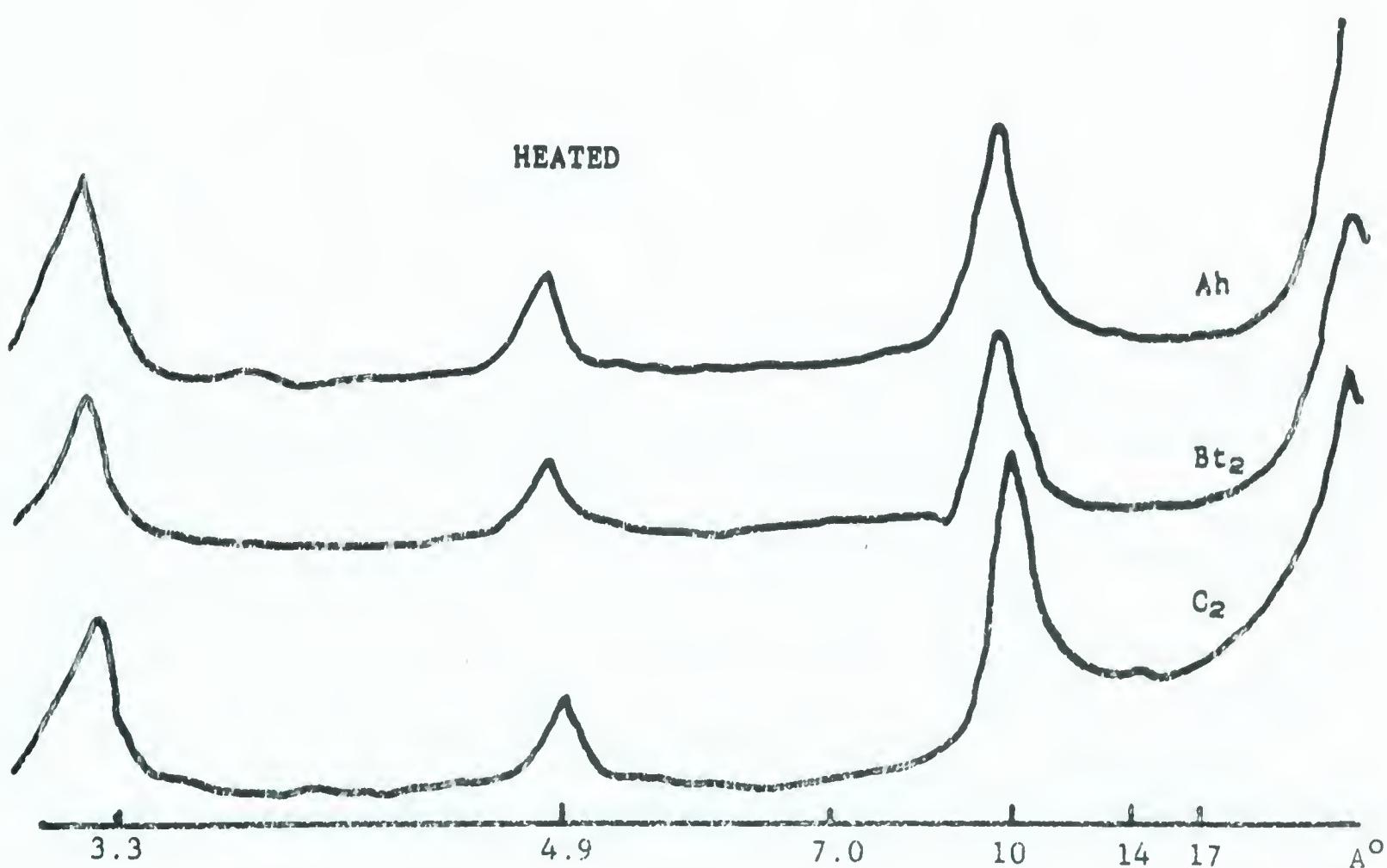
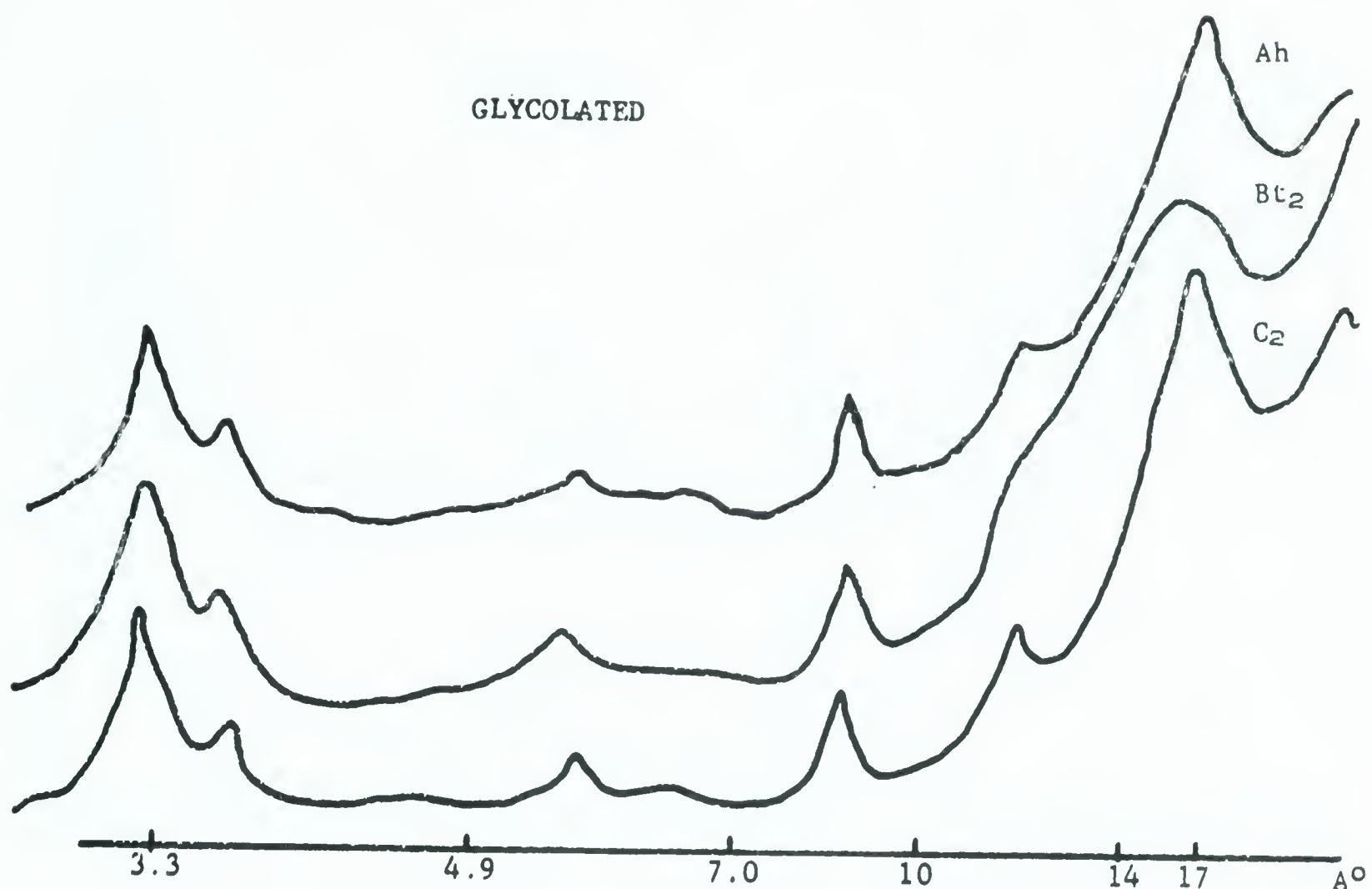


Figure 7. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 3.

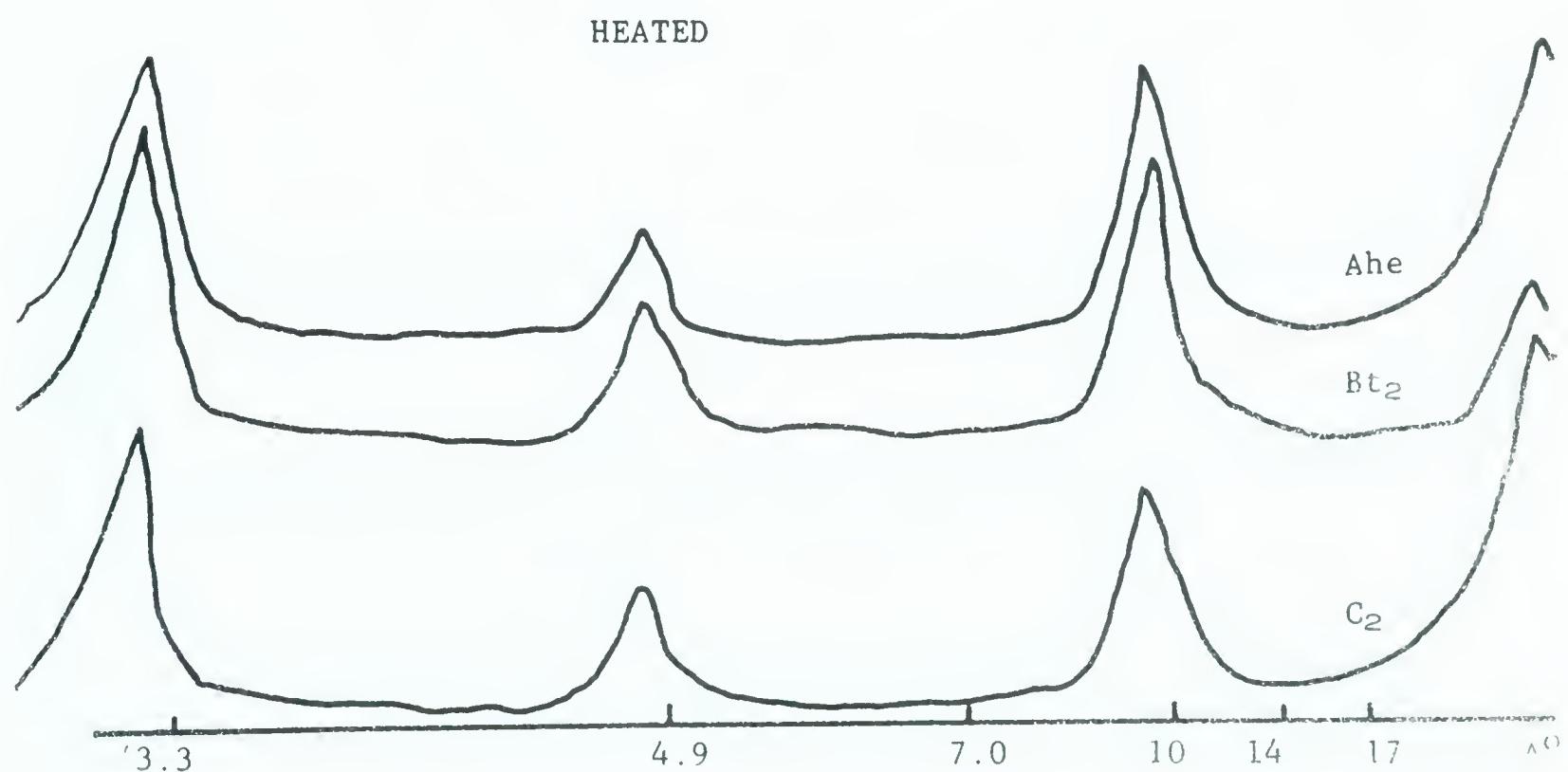
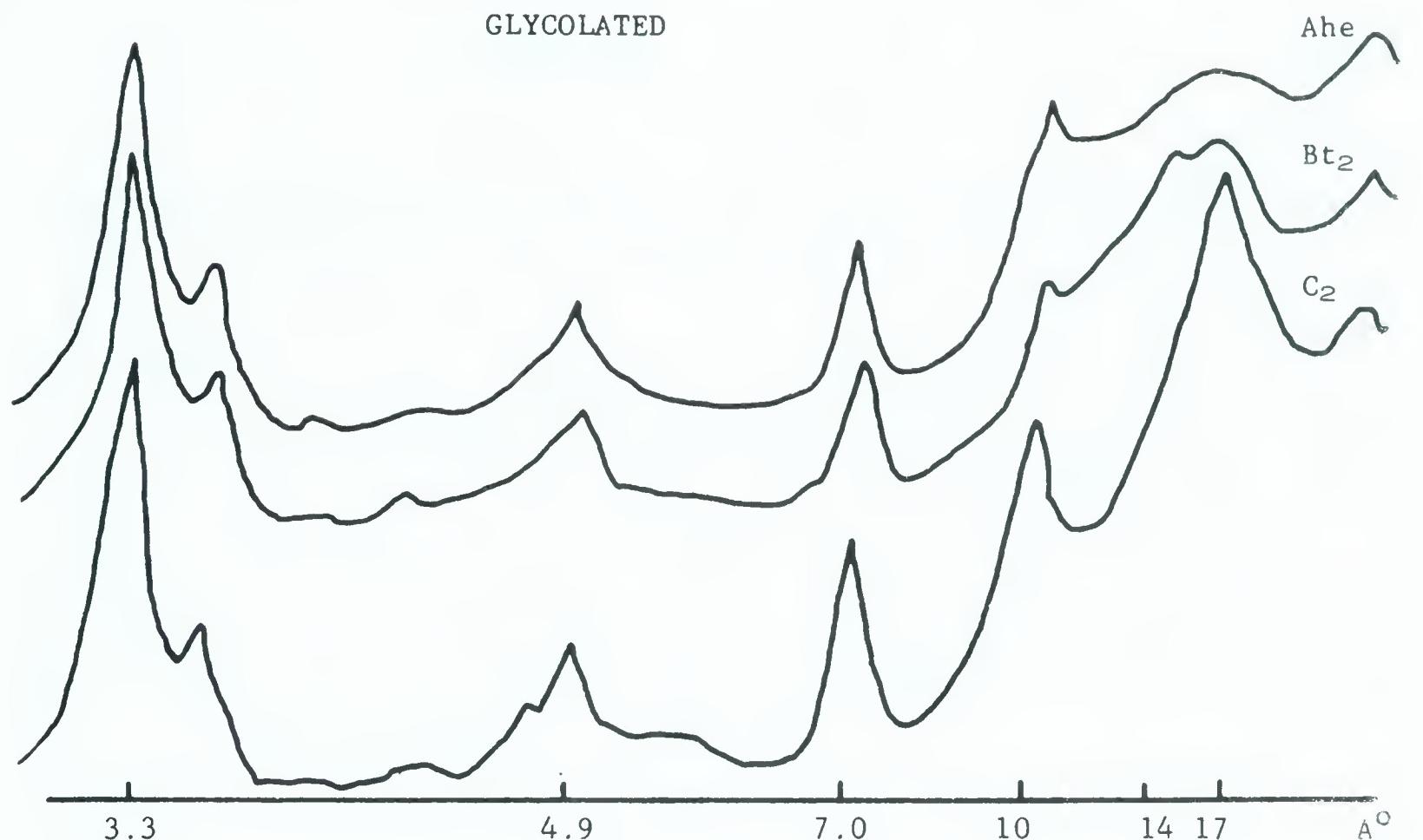


Figure 8. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 4

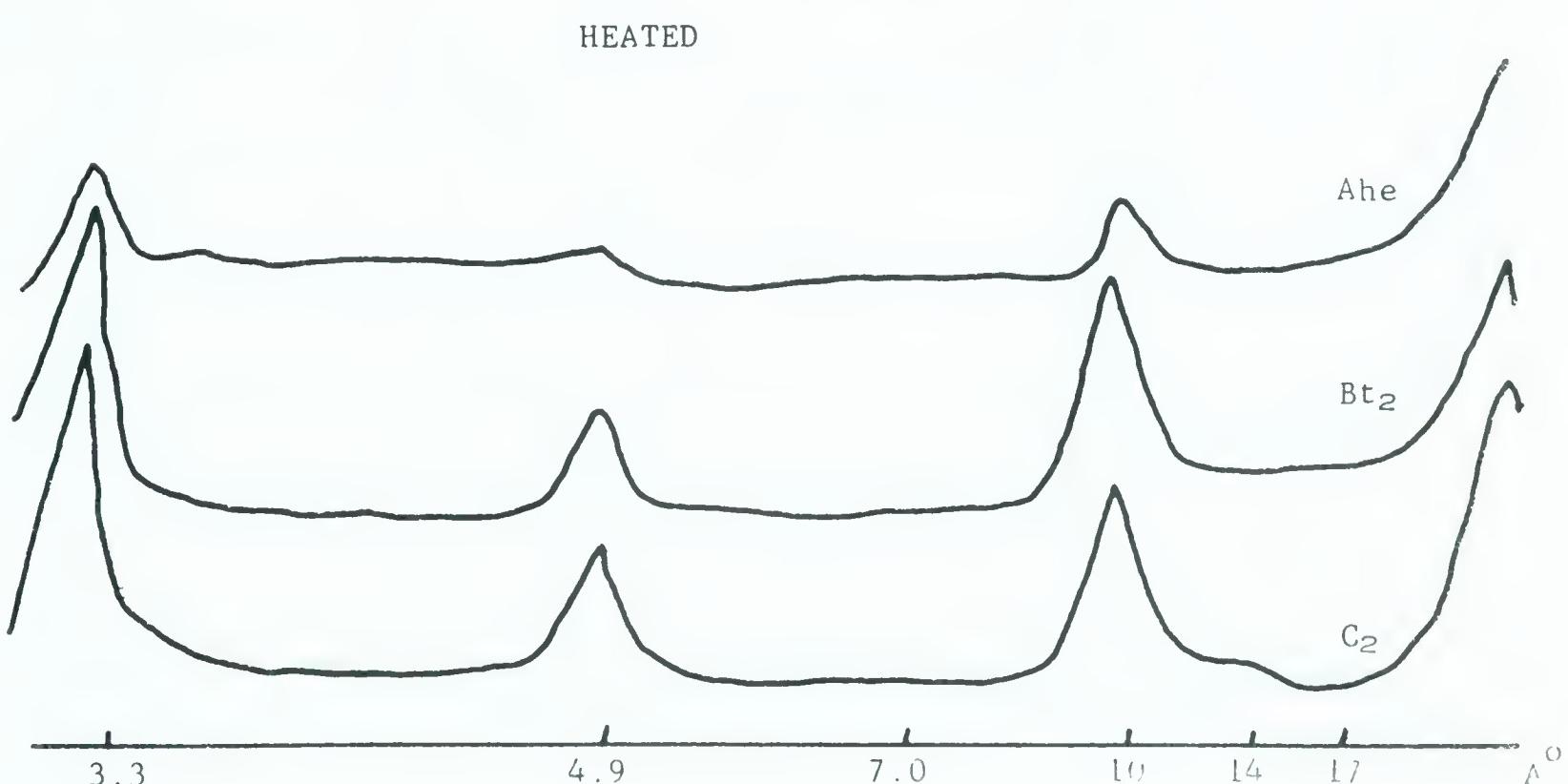
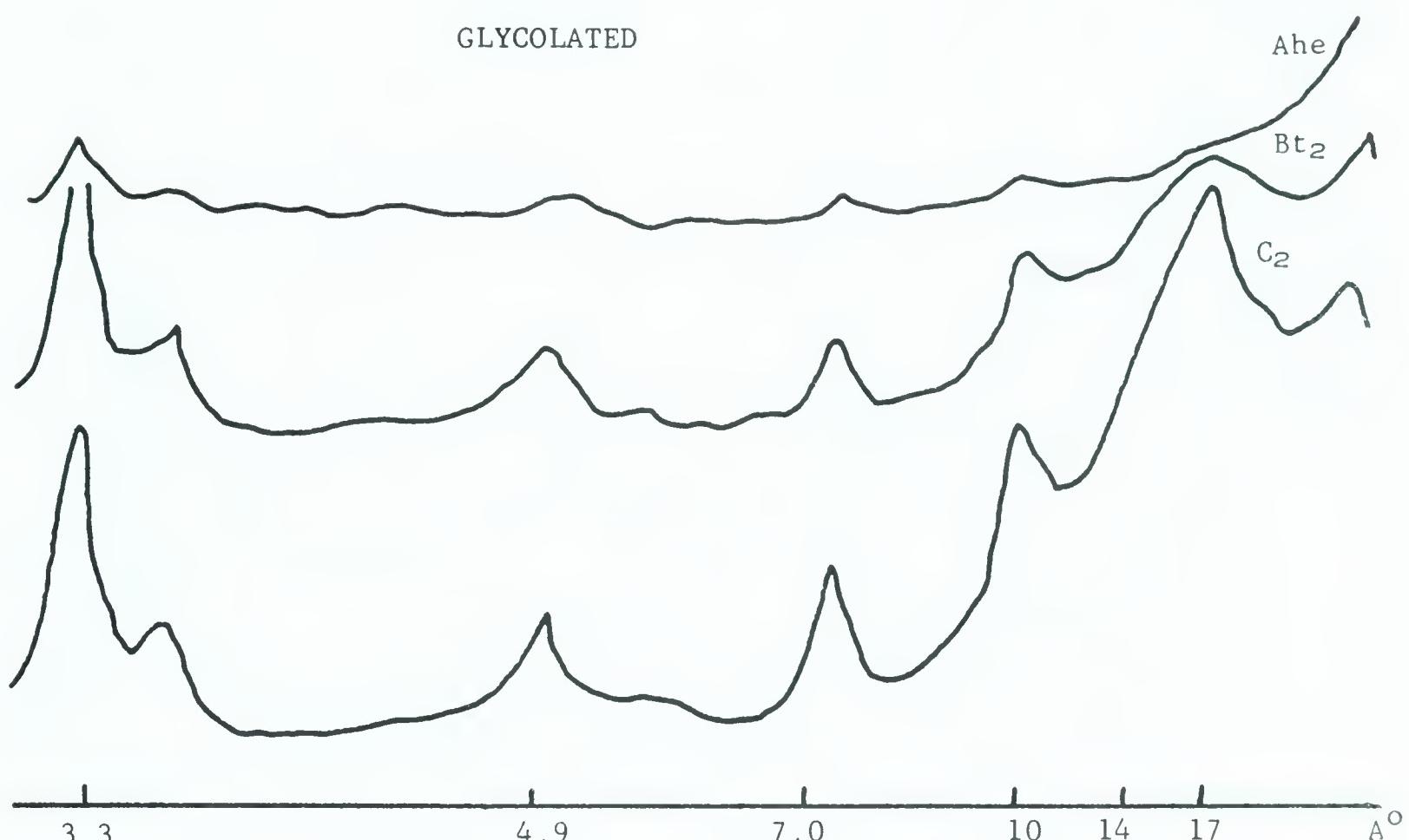


Figure 9. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 5.

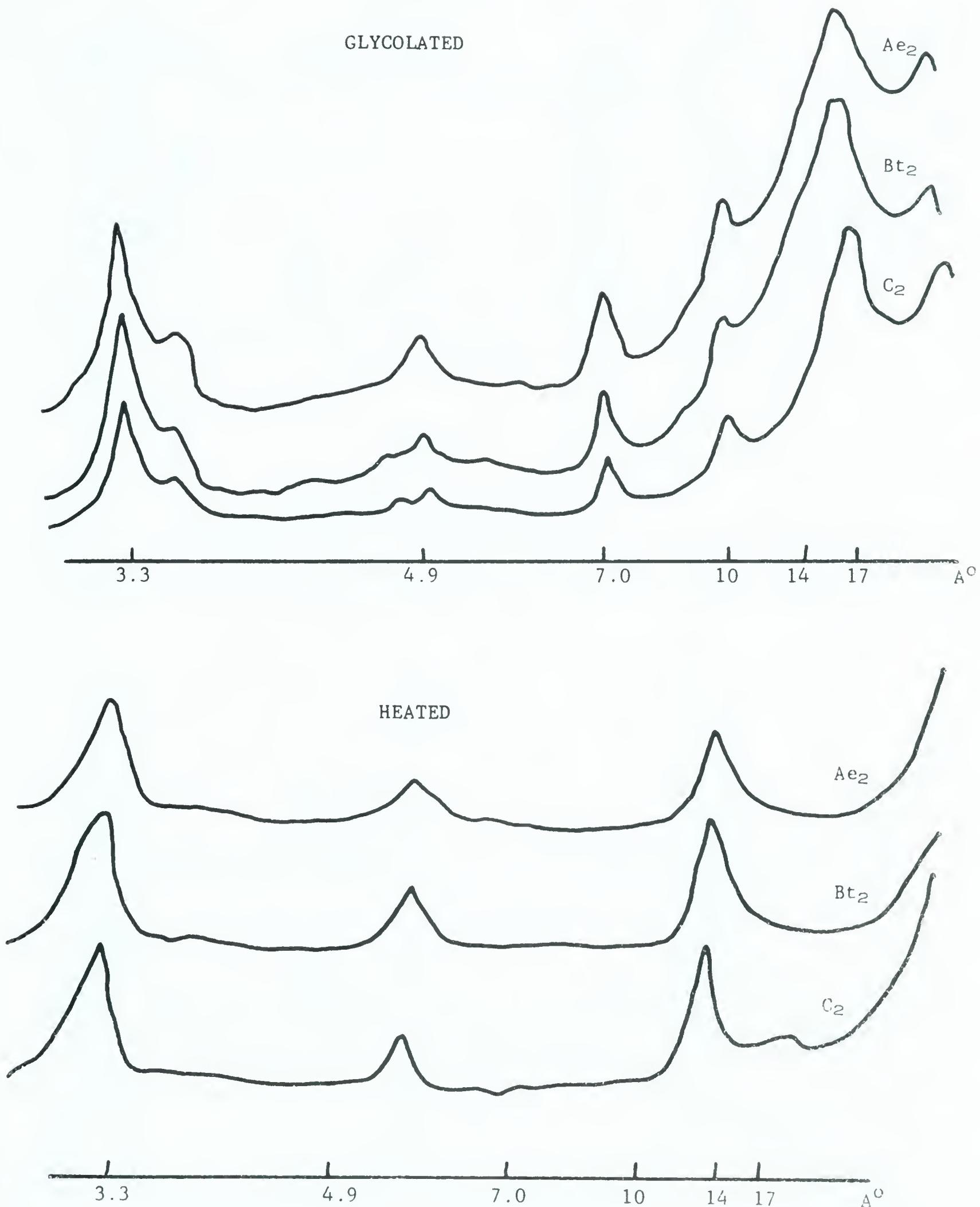


Figure 10. X-ray diffraction patterns of glycolated and heated (550°C) fine clay of site 6.

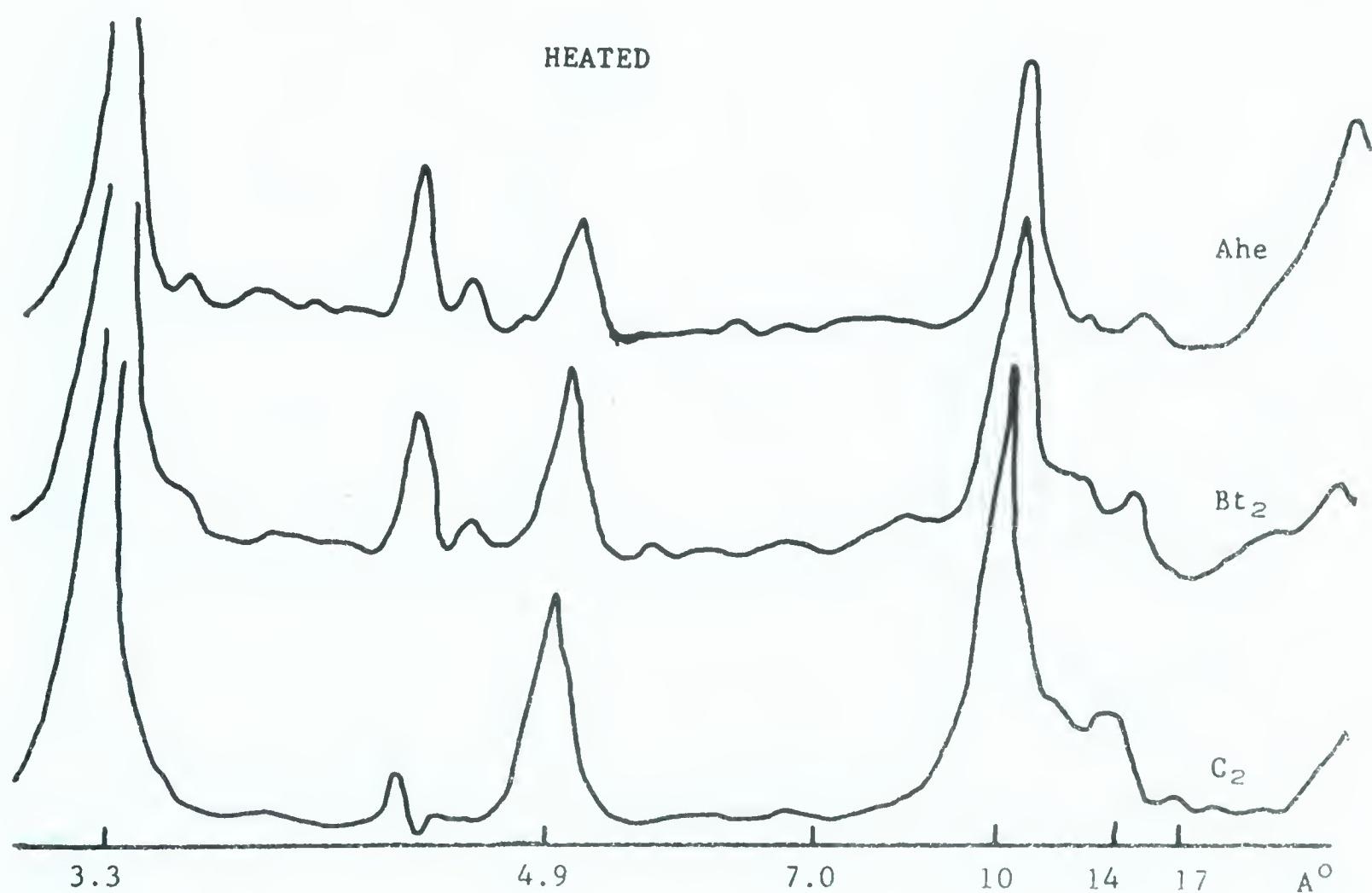
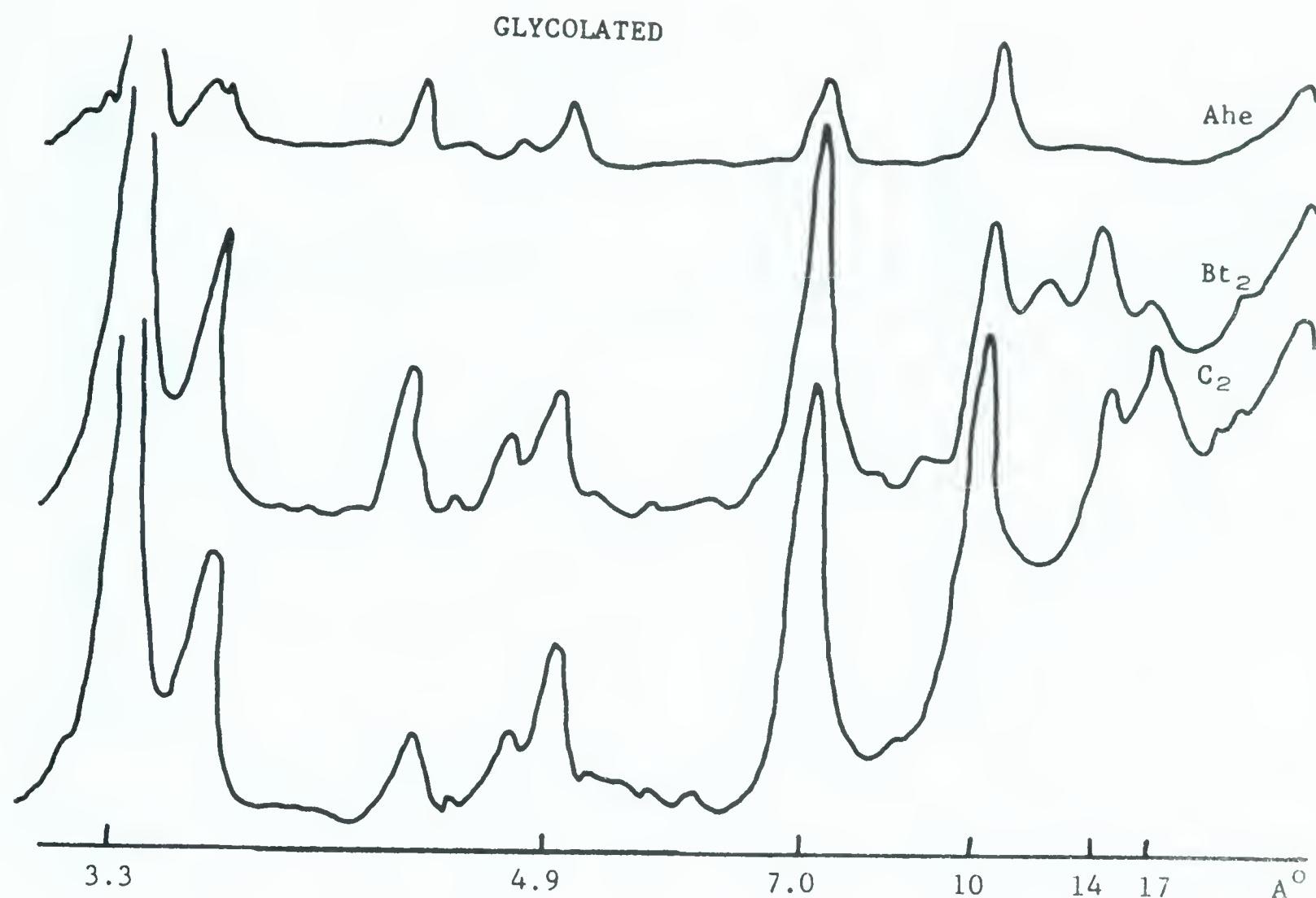


Figure 11. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 1.

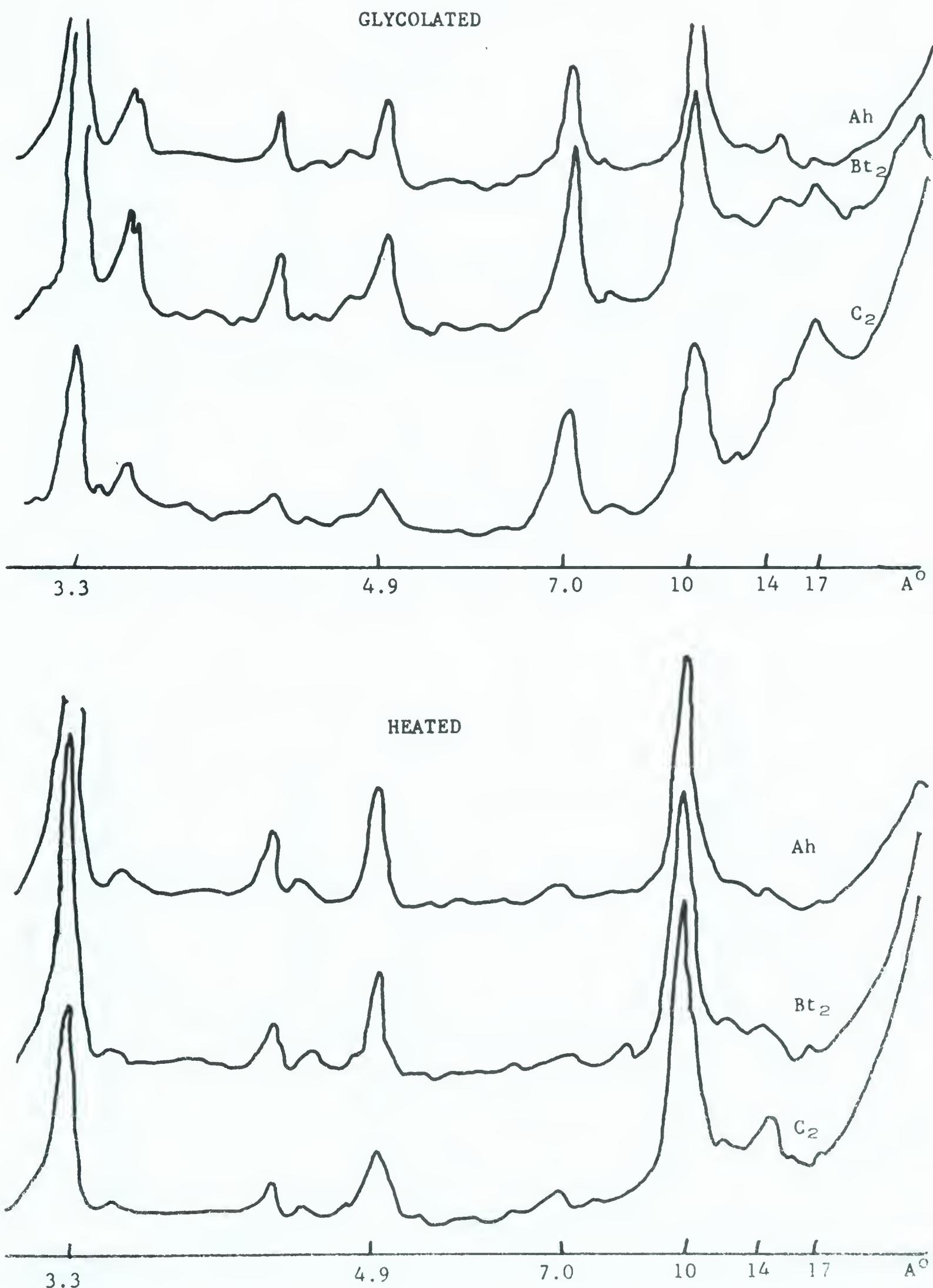


Figure 12. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 2.

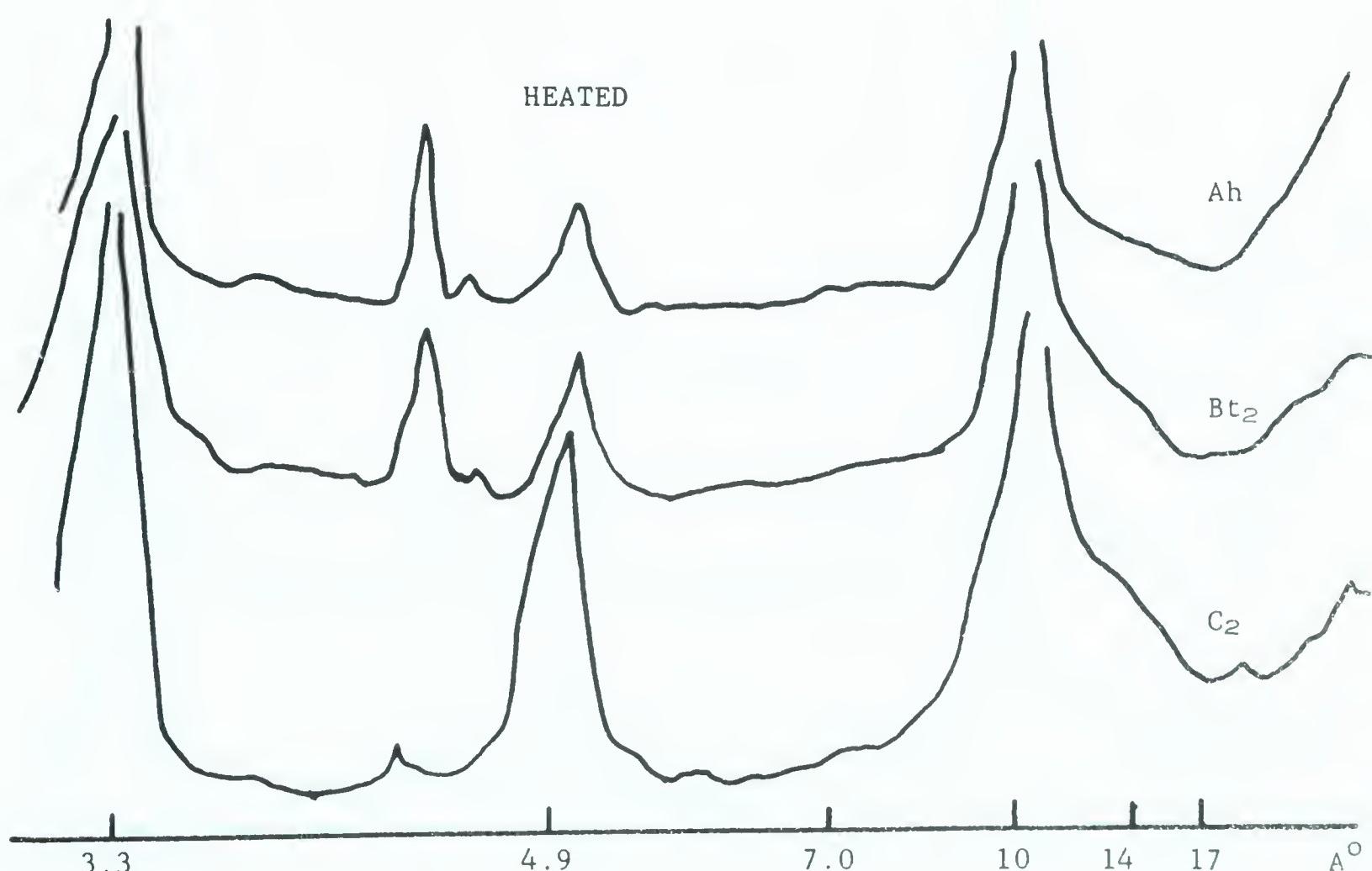
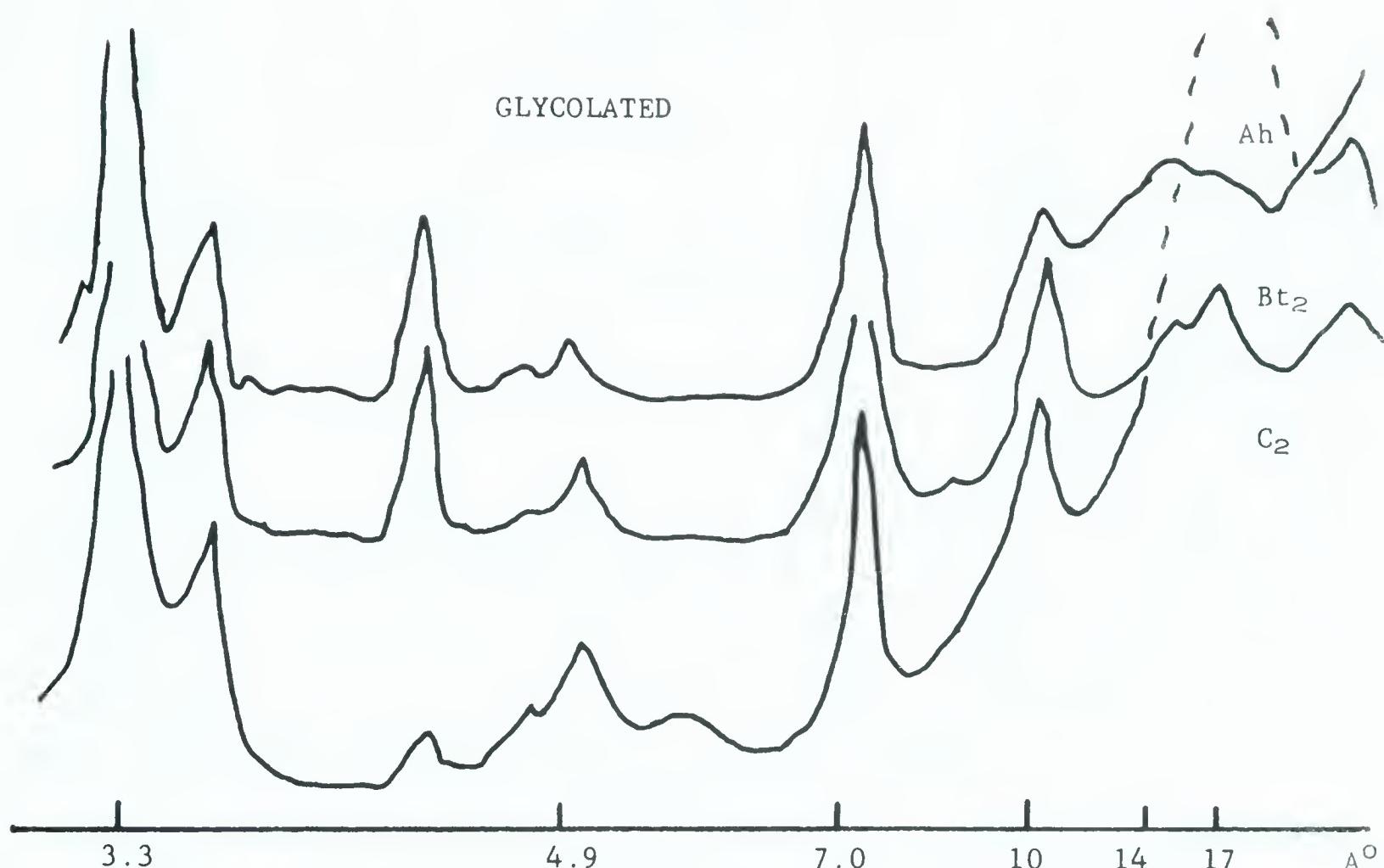


Figure 13. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 3.

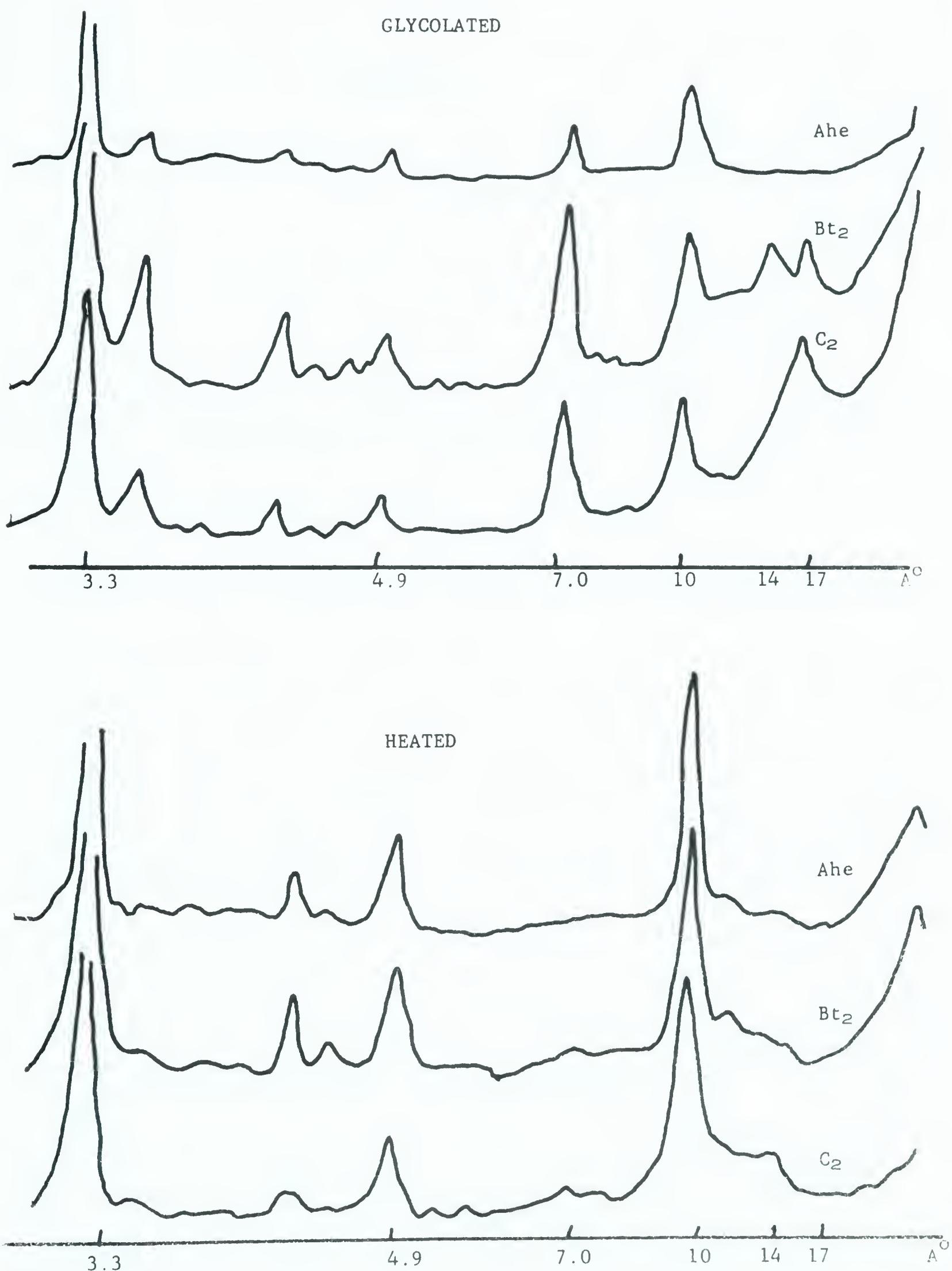


Figure 14. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 4.

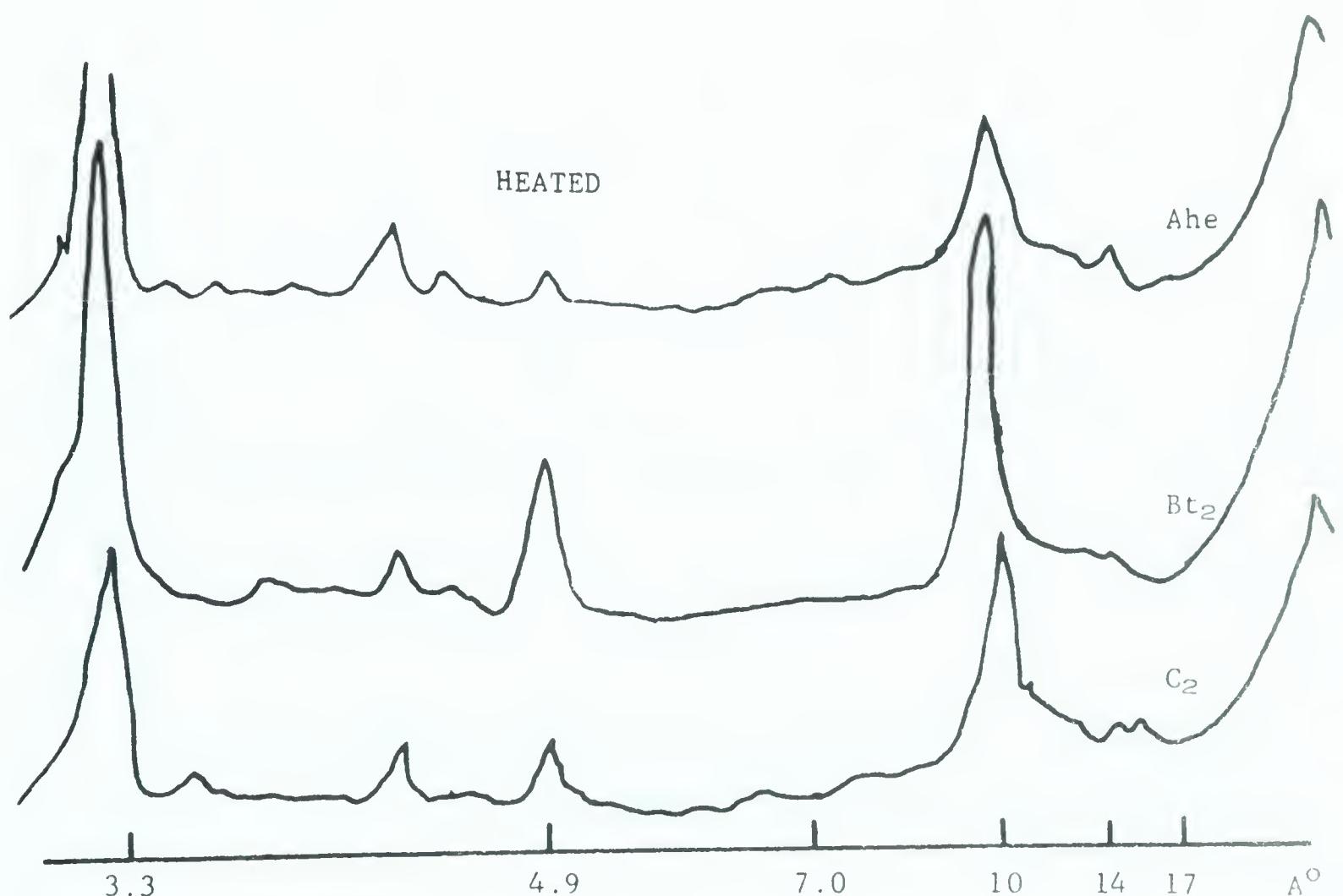
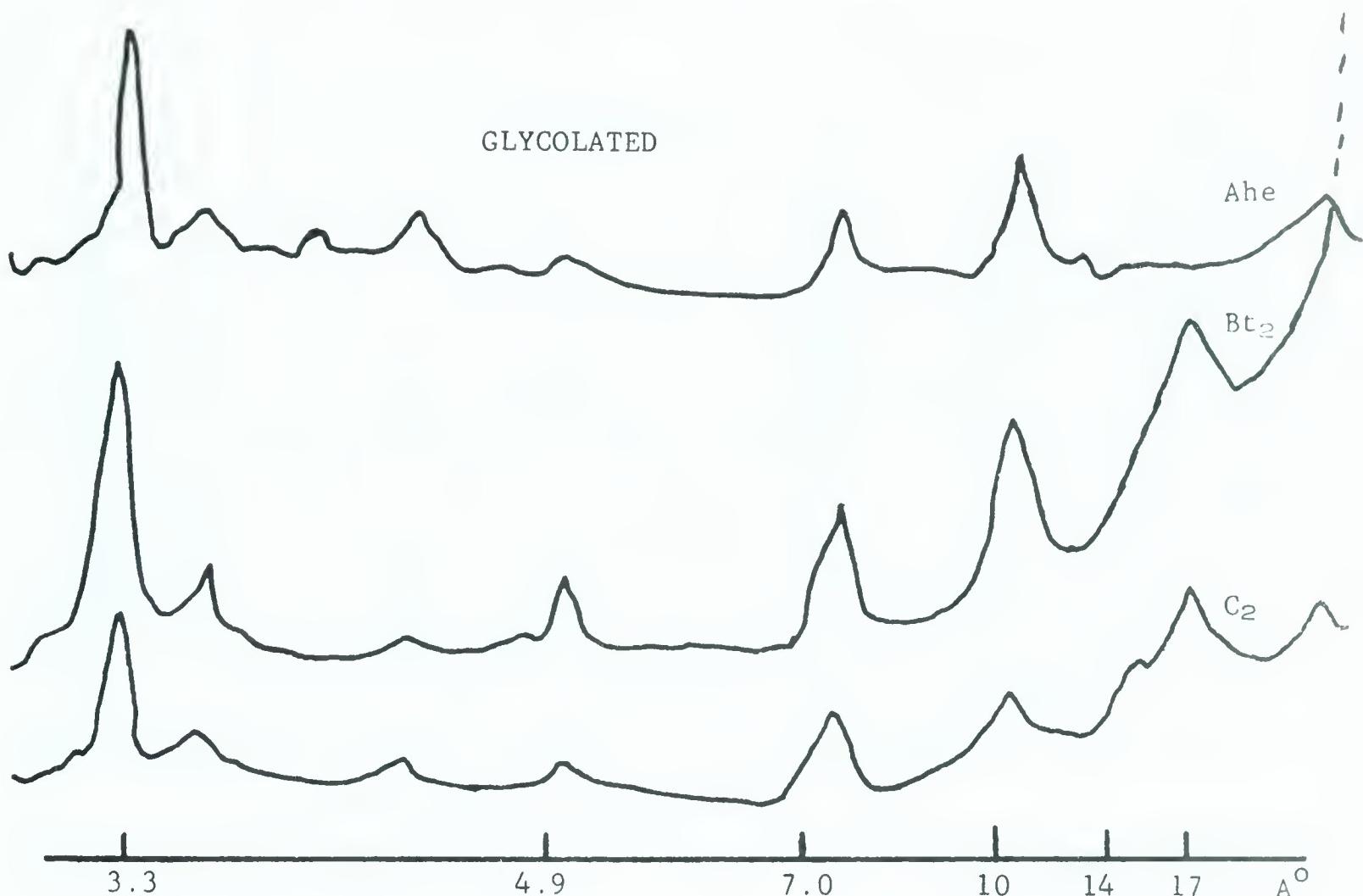


Figure 15. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 5.

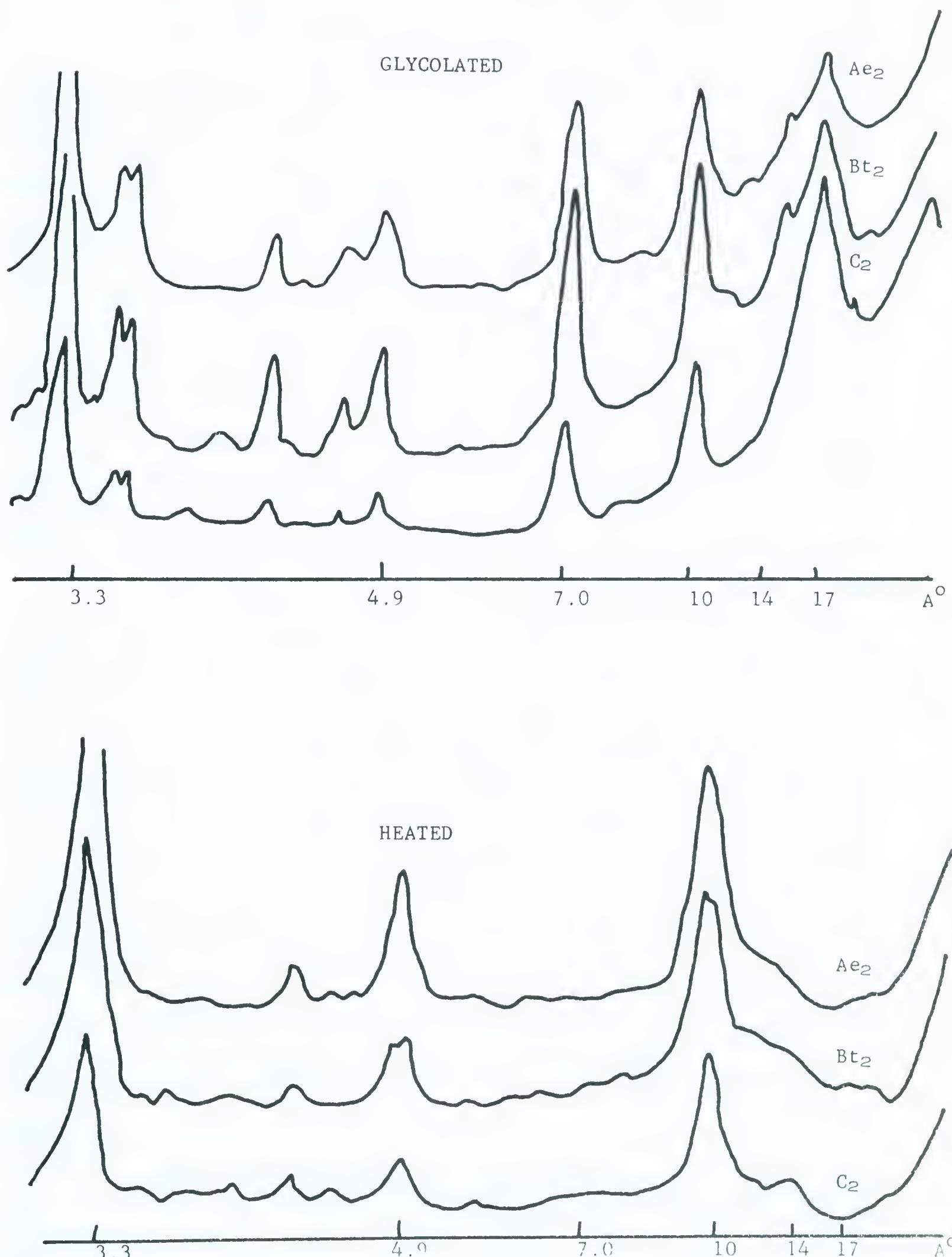


Figure 16. X-ray diffraction patterns of glycolated and heated (550°C) coarse clay of site 6.

The X-ray diffraction patterns for the fine clay fraction indicated the presence of montmorillonite, illite, and kaolinite in larger quantities than chlorite and "mixed layered" minerals. Some of the peaks of the glycolated samples were broad and poorly defined. Grim (27) stated that organic chain molecules may enter between the expanding lattices of clay minerals. It is believed that these broad poorly defined peaks, especially in the A horizons, are due to organic constituents preventing maximum glycolation and/or possible weathering of the illitic minerals to montmorillonites (79).

Montmorillonite was the major clay mineral component of the fine clay fraction. Illite and kaolinite were about equally distributed in amount in this fraction, while chlorite was not generally abundant. Mixed layering is a broad term referring to illite - chlorite - montmorillonite interstratification and exhibits "d" spacings between 10 \AA° to 14 \AA° and 14 \AA° to 16 \AA° . These minerals were more abundant in the surface horizons than in the lower solum. These patterns provided further evidence for the possible weathering of illite to montmorillonite. Fine grained quartz was present mainly in minor amounts in the fine clay fraction of all samples.

The X-ray diffraction patterns of the coarse clay fraction were well defined and sharper than those of the fine clay fraction. Illite was, in general, the major clay component of the coarse clay fraction. Kaolinite was present in minor

to major amounts. While illite tended to be more abundant in the surface horizons than in lower portions of the solum, kaolinite generally remained constant within the profile. Chlorite minerals, characterized by 14 Å "d" spacings were present in varying amounts in the coarse clay fractions for all of these soils. Approximately equal amounts of montmorillonite as well as chlorite were found to be present. It has been fairly well established that chlorite minerals are closely associated with "mix-layer" structures and that montmorillonite forms in situ as a weathering product of illite (58, 73, 79). Quartz was generally found in the same amounts in both fractions.

It was interesting to note that there was little difference in clay content of both fine and coarse clay of the Ae₂ horizon at site 6 compared with the other A horizons analyzed. The results in this study were similar to results of Alberta Grey Wooded soils (58) with two exceptions. Firstly, more chlorite was reported in these soils, especially in the coarse clay fractions. Secondly, generally less "mix-layer" minerals were present than that reported for some Grey Wooded soils. In this latter study more "mixed-layering" was evident in the coarse fraction than in the fine fraction; while in the present study, "mix-layering" was more evident in the fine clay fraction.

Light Mineral Analyses: Quantitative estimate for the 0.05 to 0.10 millimetre sand fraction having a specific gravity

less than 2.70 are given in Table X, page 60. This fraction was analyzed by X-ray techniques and fusion analyses.

The diffraction analyses showed the presence of potassium feldspar, soda-calcic feldspar, and quartz. Quartz was the dominant mineral present accounting for 70 to 90 per cent of the entire fraction and was relatively constant throughout the solum at each site. The soda-calcic feldspars were more abundant than the potassium feldspars. X-ray analyses exhibited very strong quartz peaks and weak feldspar peaks. Among the soda-calcic feldspars slightly higher amounts of the "end" members of the plagioclase series, ranging from labradorite to albite were found. There were slightly less soda-calcic feldspars reported in this study than in similar studies of Alberta soils. The potassium feldspar content was quite similar (58).

Elemental analyses data were used to calculate the percentages of potassium and soda-calcic feldspars. Quartz was determined by difference. A total feldspars to quartz ratio was calculated as an index for the amount of weathering which had occurred.

The weathering ratios indicate that there was variable dissolution of feldspars in all profiles. There was slightly less weathering in sites 1 and 3 than in 2, 4, 5, and 6. The high ratio of the Ahe at site 4 was not clearly understood but was taken to mean that this horizon was of different origin than the remaining solum. The most severe weathering, on this basis, had taken place at sites 5 and 6.

V. DISCUSSION OF PROFILE EVALUATION

Introduction: In measuring changes resulting from soil development Barshad (6) stated that it was necessary to clearly distinguish between the reactants and the resulting products. One of the main difficulties encountered in analyzing reactants and products in a soil lay in the difficulty of separating and clearly distinguishing between them. In soil studies it is assumed that the nonclay fractions represent the reactants and the clay fractions represent the products. He listed a number of criteria and assumptions which must be employed in evaluating profile development in soils and stated that the evaluation was most difficult in soils with stratified parent materials. Changes caused by soil development can be evaluated with the greatest certainty in profiles in which the clay distribution with depth indicated that the parent material had gained no clay from migration. Any clay found in the parent material must be assumed to have been present at the beginning of soil formation. Barshad stated that at no time does the clay content of the parent material exceed that of the solum as a result of pedogenic processes. If such an increase occurred, it must be assumed that the solum was of different origin than that of the underlying material (presumably parent material).

Under normal weathering conditions the rate of breakdown of primary minerals is low and most of the products do not remain long in solution even though there is a considerable dissolution of feldspars. Adsorption of ions by

cation exchange other than hydrogen favoured the formation of expanding crystal structures, such as the montmorillonite group of clay minerals. However, the presence of large amounts of organic substances, particularly those with chelating properties, prevented the formation of clay minerals from the dissolution of feldspars. This is believed to be the case in Podzolic soils.

Keller (33) had shown that kaolin minerals were expected to form as a result of weathering of aluminum silicates (feldspars) at a pH range of 7 to 4.5. At the hydrolyzing interfaces a relatively high concentration of H ions build up during or following the removal of Ca, Mg, Na, K, and Fe cations. He stated further that granitic materials (in which Na and K ions were dominant) predisposed toward the development of kaolinitic weathering products because Na and K ions tended to stabilize silica in solution and thereby expedite its removal. Thus there occurs a relative enrichment of Al ions. This enrichment of Al ions in the soils of soils undergoing podzolization had been found to be true by Pawluk (58).

Montmorillonite and illite minerals form in an environment of high concentration of Ca, Mg, Na, K, and Fe cations. In order for these minerals to form the cations must be solubilized but not leached out into the ground waters. These cations facilitated the flocculation of both SiO_2 and Al_2O_3 mutually combining them to form montmorillonite or illite. To date no evidence for re-formation of clay

minerals in Alberta soils has been found and it is likely that the weathering products of primary minerals are solubilized and leached out from the solum into the ground waters.

The direct formation of clay minerals from feldspars without complete dissolution was believed rather unlikely as alteration of feldspars to clay minerals requires a structural change. This change requires breakage of the metallic ion-oxygen bond in the parent silicate and a change from a three dimensional framework of tetrahedrons to a continuous sheet structure comprised of both tetrahedrons and octahedrons in the clay minerals.

During soil development the greatest changes are brought about by a loss or gain in clay through the process of migration. Since clay is eluviated by the downward movement of water, displacement can occur only if the clay being moved is in a suspended state. In order for the clay to accumulate it must be flocculated. Leaching water tends to deplete the electrolyte content at the surface and a consequent movement of clay and electrolyte downward takes place. Upon dehydration, flocculation occurs and further movement of clay ceases. Flocculation of downward moving clay may occur by encountering a subsoil of high electrolyte content (6, 70).

It is generally recognized that even under excessive water supply the downward movement of clay proceeds to a relatively shallow depth, ranging from 3 to 5 feet from the surface. This limiting action results from the flocculating

conditions which nearly always exist in the lower part of the profile and from the decreasing pore size distribution with depth (32).

As clay migration proceeds, bulk density tends to become greater in value as the finer pore spaces become filled by eluviated clay. Buckman and Brady (14) reported that the downward movement of clay as well as iron and aluminum oxides gave rise to very dense layers.

The depths of horizons are changed as weathering proceeds. Dissolution of feldspars in the surface horizons takes place and the water soluble products are moved downward along with the peptized clay particles. As a result the surface horizons tend to become thinner and the subsurface horizons more compacted, enriched in clays, and possibly thicker.

As a result of the dissolution of feldspars it was necessary to consider the effect their loss had on the per cent composition of the remaining, more resistant soil components. If it is assumed that the original compositions of soil material is 30 per cent feldspar, and 70 per cent quartz, a 10 per cent removal of feldspar by weathering increases the percentage of quartz by "negative enrichment".

Evaluation of Profile Development for
the Soils Under Study

In light of the foregoing discussion an attempt was made to evaluate the amount of profile development which had occurred in the soils under study. Since these soils were found on gently rolling topography and the history of the area indicated burning to have taken place, the amount of erosion, if any, which had occurred was also evaluated. The method employed was essentially that proposed by Barshad (6) except that no resistant trace "index" mineral was used but rather the loss of feldspars was considered. Since under Alberta's conditions there is little or no weathering out from the profile of clay minerals, the present amount of clay was assumed to have been present in the sola at the beginning of soil formation. That is no clay loss due to weathering had occurred but simply a re-distribution within the profile.

The evaluation of profile development and accelerated erosion (that which occurs above the normal without external influence such as fires, cultivation, etc.) are presented in Table XI (a-f), pages 91 to 96. Unfortunately the soil profile at site 6 increased continuously in clay content with depth and therefore could not be evaluated. However, a profile with similar development was evaluated from analytical results reported previously¹. Since no mineralogical data or bulk

¹ Data from Alberta Soil Survey, Research Council of Alberta

TABLE XI(a). EVALUATION OF CLAY MIGRATION FOR SITE 1

- * Average value of the various sub-horizons of C
 Total clay gained in solum 53.5 g.
 Total clay lost from solum - 2.1 g.
 Total clay gained in excess of lost 51.4 g.
 Amount of A horizon required to yield 51.4 g. is equal to:
 if 2" lost 2.1 g., then 51.4 g. was lost by:

$$x = \frac{51.4 \text{ g.} \times 2"}{2.1 \text{ g.}} = 49 \text{ inches}$$

TABLE XI(b). EVALUATION OF CLAY MIGRATION FOR SITE 2

1	2	3	4	5	6	7	8	9
Horizon	Depth in.	Present Volume c.c.	Bulk Density g./c.c.	Present Weight of Soil g.	clay < 2.0 microns %	Present Weight of Clay g.	Weight Nonclay g.	Loss of Feldspars %
Ahe	3	7.6	0.65	4.9	36	1.8	3.1	10
AB	4	10.2	0.97	9.9	49	4.8	5.1	10
Bt ₁	6	15.2	1.48	22.5	52	11.7	10.8	7
Bt ₂	4	10.2	1.41	14.4	44	6.3	8.1	7
BC	2	5.1	1.39	7.1	52	3.7	3.4	7
C	22	55.9	1.32*	73.8	42*	31.0	43.8	0

10	11	12	13	14	15	16	17
Horizon	Original Weight of Nonclay g.	Original Weight of Soil g.	Increase Due to Neg.enrich. %	Clay Due to Neg.enrich. g.	Clay Minus Clay by Neg.enrich. g.	Clay Prior to Migra- tion per 100 c.c. g.	+ clay per 100 c.c. g.
Ahe	3.4	5.2	2	0.04	1.7	22.4	- 4.9
AB	5.6	10.4	3	0.14	4.7	46.1	+ 5.4
Bt ₁	11.8	23.5	2	0.23	11.5	75.7	+13.5
Bt ₂	8.7	15.0	2	0.13	6.2	60.8	+ 2.5
BC	3.6	7.3	1	0.04	3.7	72.5	+14.1
C	31.0	73.8	0	0	31.0	55.4	0

* Average value of the various sub-horizons of C
 Total clay gained in solum 35.5 g.
 Total clay lost from solum - 4.9 g.
 Total clay gained in excess of lost 30.6 g.
 Amount of A horizon required to yield 30.6 g. is equal to:
 if 3" lost 4.9 g., then 30.6 g. was lost by:

$$x = \frac{30.6 \text{ g.} \times 3''}{4.9 \text{ g.}} = 19 \text{ inches}$$

TABLE XI(c). EVALUATION OF CLAY MIGRATION FOR SITE 3

* Average value of the various sub-horizons of C	56.3 g.
Total clay gained in solum	-30.5 g.
Total clay lost from solum	
Total clay gained in excess of lost	25.8 g.
Amount of A horizon required to yield 25.8 g. if 3" lost 12.1 g., then 25.8 g. was lost by:	
x = <u>$\frac{25.8 \text{ g.} \times 3"}{12.1 \text{ g.}}$</u>	= 6 inches

TABLE XI(d). EVALUATION OF CLAY MIGRATION FOR SITE 4

1	2	3	4	5	6	7	8	9
Horizon	Depth in.	Present Volume c.c.	Bulk Density g./c.c.	Present Weight of Soil g.	Clay < 2.0 microns %	Present Weight of Clay g.	Present Weight of Nonclay g.	Loss of Feldspars %
Ahe	3.5	8.9	0.66	5.9	31	1.8	4.1	0
AB	4.5	11.4	1.18	13.4	33	4.4	9.0	11
Bt ₁	3	7.6	1.28	9.7	40	3.9	5.8	11
Bt ₂	3	7.6	1.28	9.7	47	4.6	5.1	11
BC	3	7.6	1.31	10.0	46	4.6	5.4	11
C	26	66.0	1.33*	87.8	37*	32.5	55.3	0

10	11	12	13	14	15	16	17
Horizon	Original Weight of Nonclay g.	Original Weight of Soil g.	Increase Due to Neg.enrich. %	Clay Due to Neg.enrich. g.	Clay Minus Clay by Neg.enrich. g.	Clay per 100 c.c. g.	Clay Prior to Migrat- ion per 100 c.c. g.
Ahe	4.1	5.9	1	0.02	1.8	20.2	24.4
AB	10.0	14.4	3	0.13	4.3	37.7	43.7
Bt ₁	6.4	10.3	2	0.08	3.8	50.0	47.4
Bt ₂	5.7	10.3	2	0.09	4.5	59.2	47.4
BC	6.0	10.6	8	0.37	4.2	55.3	48.5
C	55.3	87.8	0		32.5	49.2	49.2

* Average value of the various sub-horizons of C	
Total clay gained in solum	21.2 g.
Total clay lost from solum	-10.2 g.
Total clay gained in excess of lost	11.0 g.
Amount of A horizon required to yield 11.0 g. is equal to: if 3.5" lost 4.2 g., then 11.0 g. was lost by:	
$x = \frac{11.0 \text{ g.} \times 3.5"}{4.2 \text{ g.}}$	= 9 inches

TABLE XI(e). EVALUATION OF CLAY MIGRATION FOR SITE 5

* Average value of the various sub-horizons of C

Total clay gained in solution 32.6 g.

Total clay lost from solum -23.5 g.

Total clay gained in excess of lost Amount of A horizon required to yield g.i.a g.1 g.

31 A horizon required to yield 6.1 g. was lost by:
if 5" lost 11.8 g., then 9.1 g. is lost.

$$x = \frac{9.1 g \cdot x 5''}{11.8 g} = 4 \text{ inc}$$

TABLE XI(f). EVALUATION OF CLAY MIGRATION FOR SITE 6

* Average value of the various sub-horizons of C		
Total clay gained in solum	75.4 g.	
Total clay lost in solum	-53.2 g.	
Total clay gained in excess of lost	22.2 g.	
Amount of A horizon required to yield 22.2 g. is equal to: if 4" lost 50.4 g., then 22.2 g. was lost by:		
$x = \frac{22.2 \text{ g.} \times 4"}{50.4 \text{ g.}}$	2 inches	

density values were available for the sample, data was supplemented by that obtained for site 6.

To facilitate the evaluation of profile development the following assumptions were felt feasible:

1. Clay minerals, under Alberta conditions, do not weather out from the profile but are simply translocated.
2. The C horizon is similar to the original material from which the soil had formed, thus the clay present in the C was a measure of the clay content throughout the profile.

To aid in the understanding of the calculations involved in Table XI(a-f), a detailed explanation of each column follows using the Ahe of site 1 as an example:

- 1 & 2. Columns 1 and 2 were obtained directly from profile descriptions in Tables I to VI, pages 35 to 40.
3. Present volume per horizon was calculated by assuming a 1 sq. cm. area and converting to volume basis, i.e.,
$$2.54 \text{ cm.} \times 2 \times 1 \text{ cm.}^2 = 5.1 \text{ c.c.}$$
4. Bulk density values were obtained from the determinations reported in Table VII(a-f), pages 47 to 52.
5. Present weight of soil per horizon was determined by multiplying the present volume by the bulk density for each horizon, i.e., $5.1 \text{ c.c.} \times 1.10 \text{ g./c.c.} = 5.6 \text{ g.}$
6. Clay per cent values were obtained from total clay per cent in Table VII(a-f), pages 47 to 52.

- 7 & 8. Present weight of clay and nonclay were calculated by multiplying the per cent clay by the per cent weight of soil, i.e., $\frac{33}{100} \times 5.6 \text{ g.} = 1.8 \text{ g.}$ and the remainder $5.6 \text{ g.} - 1.8 \text{ g.} = 3.8 \text{ g.}$ is nonclay.
9. Loss of feldspars was based on loss of material from the nonclay fraction reported in Table X, page 60.
- 10 & 11. The original weight of nonclay and soil refer to the weight of the materials after clay migration but prior to feldspar weathering, i.e., original nonclay = present weight of nonclay plus loss due to feldspars weathering multiplied by weight of nonclay, or
- $$3.8 \text{ g.} + \left(\frac{2}{100} \times 3.8 \text{ g.} \right) = 3.9 \text{ g.}$$
- Original weight of soil is equal to the sum of original nonclay plus present weight of clay (since clay is assumed not to be weathered) or $3.9 \text{ g.} + 1.8 \text{ g.} = 5.7 \text{ g.}$
- 12 & 13. Clay increase due to "negative" enrichment was calculated to correct for the per cent increase in clay in the horizon due to the loss of feldspars. This figure was arrived at by dividing column 7 (present weight of clay) by column 11 (original weight of soil), then multiplying by 100 to change to per cent and subtracting from clay per cent present at that horizon. This is the result reported in column 12. Column 13 is the percentage of column 12 multiplied by the weight of clay present to convert to a weight basis,

i.e., clay increase due to negative enrichment =
$$32\% - \left(\frac{1.8}{5.7} \text{ g.} \times 100 \right) = 1\%.$$

Clay due to negative enrichment = $1.8 \text{ g.} \times 1\% = 0.02 \text{ g.}$

14. Present clay minus clay by negative enrichment corrects the weight of clay due to the loss from the profile of feldspars, i.e., $1.8 \text{ g.} - 0.02 \text{ g.} = 1.78 \text{ g.}$
 $\doteq 1.8 \text{ g.}$
15. Clay per 100 c.c. was determined by dividing column 14 by column 3 and multiplying by 100, i.e.,
$$\frac{1.8 \text{ g.}}{5.1 \text{ c.c.}} \times 100 \text{ c.c.} = 35.3 \text{ g.}$$
16. Clay prior to migration per 100 c.c. was calculated by multiplying the clay content of the C (parent material) in column 6 by the bulk density at each horizon in order to correct for movement out of the horizon and a proportionate loss of volume of the horizon, i.e., $\frac{34\%}{100} \times 1.10 \text{ g./c.c.} = 37.4 \text{ g./100 c.c.}$
17. Column 17 (\pm clay per horizon) was calculated by subtracting column 16 from column 15. A negative sign indicates clay removal while a positive sign indicates clay accumulation.

Table XI(a-f) exhibit a calculation of the amount of A horizon required to yield the clay which had accumulated in the lower sola of the soils under study. This may serve as a measure of the amount of accelerated erosion which had occurred

from a soil horizon similar to that present in the A horizon. The amount of A horizon required to yield the amount of clay lost varies from a maximum of 49 inches to a minimum of 2 inches. This would definitely indicate that erosion had occurred from these soils tending to retard their development at a dynamic equilibrium different from that of the surrounding soils which were found on a more level topography. The results, in general, showed that where a relatively thick Ae (> 5 inches) or an Ae of low clay content was present little accelerated erosion had occurred.

It should not be felt, however, that each profile had actually lost up to 49 inches from the sola as a result of erosion. The values calculated were based on the A horizon as it exists at the present time. If it is assumed that the original A horizon (lost by erosion) was an Ae with a clay content of approximately 15 to 20 per cent, rather than 30 per cent, a value of approximately 2 to 4 inches as reported at sites 5 and 6 would be found for each site. The present surface horizons at some of the sites may be an AB horizon or the upper portion of a B horizon (exhibited by the high clay content) which is undergoing humification and eluviation as a result of the mixed grass and forest vegetation.

The characteristics of the surface horizons reported in Tables I to VI confirm this discussion since the soil exhibiting the greatest amount of erosion (site 1) had a texture of silty clay loam and a sub-angular block structure

in the A horizon. Both of these characteristics are more typical of B horizons than silty loam Ah and/or Ahe occurring in the soil sola of the adjacent more level areas. The present surface horizons of the soils under study could be designated possibly as an A(B)he indicating that erosion of the A had taken place and a "new" A horizon had formed from the AB or B horizon.

VI. SUMMARY AND CONCLUSIONS

The purpose of this investigation was to evaluate the mode and amount of development of the Judah series mapped in the Peace River area of northern Alberta in an endeavour to classify them according to the Canadian Soil Classification Scheme. There was less emphasis placed upon attempting to modify the existing scheme for differentiation among Regosolic, Brunisolic, and Podzolic soils.

The characterization of the soils was carried out by conducting physical, chemical, and mineralogical analyses. Some of the major conclusions of the study include:

1. Physical analyses show that there was an accumulation of clay sized materials in the B horizons of all soils studied. The soils were characterized by stratified parent materials of generally Si CL to Si C texture.
2. In some profiles there was little evidence of visible eluviation. However, there was definite illuviation since all the B horizons met the requirements of a Bt horizon as defined in the "7th Approximation".
3. The chemistry of the solum was found to be in accord with those reported for Grey Wooded soils. The cation exchange capacity and exchangeable cations were similar to those reported for soils in the area. There was an accumulation of free iron oxides in the B horizons.
4. The C:N ratio of the surface horizons met the requirements of an Orthic Dark Grey Chernozemic or Dark Grey Wooded Sub-group.

5. Parent materials were found to be calcareous in nature and to be of marine origin.
6. The clay mineral suite was found to be similar to Grey Wooded soils in Alberta, with no indication of clay mineral synthesis in the B horizons.
7. Light mineral analyses indicated that there was little loss of feldspars from the sand fraction as a result of weathering, even though a considerable portion of the feldspar content had been weathered out from the sola.
8. Erosion from the surface had taken place tending to retard the development of these soils. However, the amount which had occurred was difficult to assess because the nature of the present A horizon was felt to be different from that from which the soils had initially formed.
9. None of the soils were considered to be Brunisolic on the basis of the presence of definite Bt horizons.
10. None of the soils were considered to be Regosolic on the basis of the presence of marked horizon development.
11. Soils at sites 1, 2, and 5 were classified as Dark Grey Wooded, at sites 3 and 4 as Orthic Dark Grey Chernozemic, and at site 6 as Orthic Grey Wooded. The color criteria for the Dark Grey Chernozemic and Dark Grey Wooded Sub-groups are as follows:

Dark Grey Chernozemic: The Ah, Ahe or (Ah.Ahe) combination should be over 3 inches, or of sufficient thickness to produce 5 inches of mixed surface below

a leaf mat, or an Aa horizon, with values between 3.5 and 5.0 dry and chroma of less than 2.5.

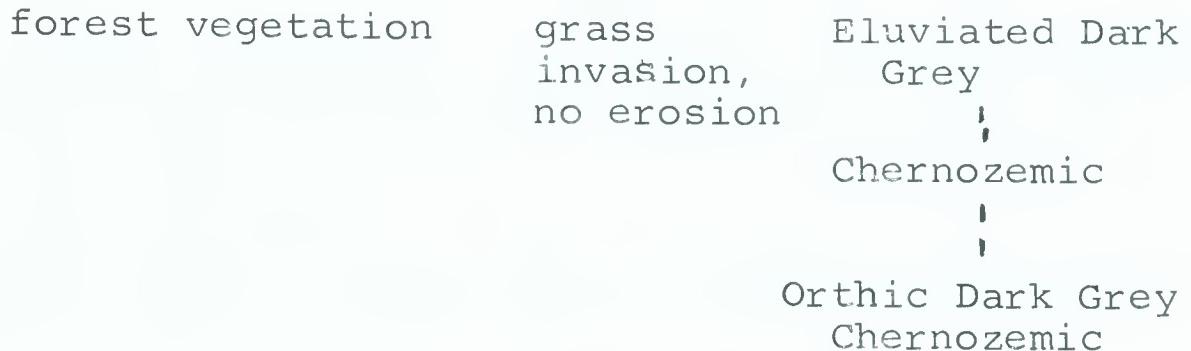
Dark Grey Wooded: Thin, less than 4 inches, chernozemic or degraded chernozemic Ah or Ahe over a light colored Ae horizon underlain by a Bt, or soils with thinner Ah but with prominent Aeh. The mixed surface layer (Aa) has a color value between 3.5 and 6 dry and a chroma less than 2.5.

In general chroma were $\frac{1}{2}$ unit greater than that acceptable for either the Dark Grey Wooded or Dark Grey Chernozemic Sub-groups. However, no other Sub-group definition would fit as closely as the above two. The greater chroma values were believed to be partially inherent to the parent materials thus affecting the colors of the sola of these soils. The fact that the colors of the surface horizons resemble those normally reported for B horizons and the rather high clay content of some of the A horizons further suggested that their present surface horizon was formed from an original AB or B horizon after the removal of the A horizon by erosion. This was most obvious at sites 1, 2, 4, and 5.

12. It is believed that with continued grass vegetation all these soils will become Orthic Dark Grey Chernozemic as the result of increased humification and sod formation darkening the surface horizons to meet the definition

of this Sub-group. The sequence of development proposed for these soils would probably be:

Regosolic -- Brown Wooded -- Grey Wooded -- Dark Grey Wooded



or

-- Grey Wooded -- Dark Grey Wooded
fire,
partial ero-
sion of A
horizon and
grass invasion

or

-- Grey Wooded -- ?
fire, complete
erosion of A
horizon and
grass invasion
(Similar to
Dark Grey Cher-
nozemic except
new Ah formed
from B horizon
material)

13. These soils closely resemble the regraded Dark Grey and Grey Forest Soils of Russia.

VII. BIBLIOGRAPHY

1. Association of Official Agricultural Chemists. 1955. Official methods of analysis. 8th ed. Washington 4, D.C.
2. Atkinson, H. J., G. R. Giles, A. J. MacLean, and J. R. Wright. 1958. Chemical methods of soil analysis. Contrib. 169 (rev.) Chemistry Division, Science Service, Can. Dept. Agr. Ottawa.
3. Aubert, G., and P. Duckaufour. 1956. Project de classification des sols. Trans. Intern. Congr. Soil Sci. 6th Congr. Paris E. 597-604.
4. Avery, B. W. 1956. A classification of British soils. Trans. Intern. Congr. Soil Sci. 6th Congr. Paris E. 279-285.
5. Baldwin, M., C. E. Kellogg, and J. Thorp. 1938. Soil Classification. U.S. Dept. Agr. Yearbook.
6. Barshad, I. 1958. Soil development. "Chemistry of the Soil". A.C.S. Monograph 126. Ed. by Firman E. Bear. Reinhold Publ. Co., New York, N.Y.
7. Barshad, I. 1960. X-ray analysis of soil colloids by a modified paste method. Proc. 7th Nat'l. Conf. on Clays and Clay Min. 350-364.
8. Bartelli, L. F., and R. T. Odell. 1960. Laboratory studies and genesis of clay enriched horizon in the lowest part of the solum of some Brunizem and Gray-Brown Podzolic soils in Illinois. Soil Sci. Soc. Amer. Proc. 24: 390-395.
9. Baver, L. D. 1959. Soil physics. 3rd ed. John Wiley and Sons, Inc., New York, N.Y.
10. Bayrock, L. A. 1962. Heavy minerals in till of central Alberta. J. Alta. Soc. Pet. Geol. 10: 171-184.
11. Bloomfield, C. 1954. A study of podzolization. J. Soil Sci. 5: 46-56.
12. Brown, J. C. 1943. A rapid method of determining exchangeable hydrogen and total exchangeable bases of soils. Soil Sci. 56: 353-357.
13. Brydon, J. E., and F. J. Sowdon. 1959. A study of the clay-humus complexes of a Chernozemic and a Podzol soil. Can. J. Soil Sci. 39: 136-143.

14. Buckman, H. O., and N. C. Brady. 1960. The nature and properties of soils. 6th ed. The Macmillan Co., New York, N.Y.
15. Caldwell, A. C., R. S. Farnham, and F. L. Hammers. 1955. A chemical and mineralogical study of clay minerals from several Gray-Brown Podzolic soils of Minnesota. *Soil Sci. Soc. Amer. Proc.* 19: 351-354.
16. Cann, D. B., and E. P. Whiteside. 1955. A study of the genesis of a Podzol-Gray-Brown Podzolic intergrade soil profile in Michigan. *Soil Sci. Soc. Amer. Proc.* 19: 497-501.
17. Cheng, K. L., and R. H. Bray. 1951. Determination of calcium and magnesium in soil and plant material. *Soil Sci.* 72: 449-558.
18. Cline, M. G. 1949. Profile studies of normal soils of New York: I. Soil profile sequences involving Brown Forest, Gray-Brown Podzolic and Brown Podzolic soils. *Soil Sci.* 68: 259-272.
19. Cline, M. G. 1955. Soils and soil associations of New York. *Cornell Ext. Bull.* 930. New York State College Agr. N. Y.
20. Dickson, B. A., and R. L. Crocker. 1953. A chronosequence of soils and vegetation near Mount Shasta, California. *J. Soil Sci.* 4: 142-154.
21. Doughty, J. L. 1941. The advantages of soil paste for routine pH determinations. *Soil Sci.* 22: 135-138.
22. Duckaufour, P. 1960. *Precis de pedologie*. Masson & C E'diteurs, 120 Boulevard, Saint-Germain, Paris.
23. Frei, E., and M. G. Cline. 1949. Profile studies of normal soils of New York: II. Micromorphological studies of the Gray-Brown Podzolic - Brown Podzolic soil sequences. *Soil Sci.* 68: 333-343.
24. Frindland, V. M. 1958. Podzolization and illimerization. *Pochvovedenie.* No. 1: 24-32.
25. Gardner, D. R., and E. P. Whiteside. 1952. Zonal soils in the transition region between the Podzolic and Gray-Brown Podzolic regions in Michigan. *Soil Sci. Soc. Amer. Proc.* 17: 137-144.
26. Gravenor, C. P., and L. A. Bayrock. 1961. Glacial deposits of Alberta. "Soils in Canada". Ed. R. F. Legett. Royal Soc. Can. Spec. Pub. 3. Univ. of Toronto Press.

27. Grim, R. E. 1953. Clay mineralogy. McGraw-Hill Book Co., Inc. New York, N.Y.
28. Ivanova, Y. N., and N. N. Rozov. 1958. An attempt at a systematic classification of the soils in the steppe zone of the U.S.S.R. *Pochvovedenie*. No. 12: 1349-1358.
29. Jackson, M. L. 1956. Soil chemical analysis - Advanced Course. Madison, Univ. of Wis. Pub'd. by the author.
30. Jackson, M. L., J. D. Whittig, and R. P. Pennington. 1949. Segregation procedure for the mineralogical analysis of soils. *Soil Sci. Soc. Amer. Proc.* 14: 77-81.
31. Jackson, M. L., Y. Hseung, R. B. Corey, E. J. Evans, and R. C. Vanden Heuvel. 1952. Weathering sequence of clay size minerals in soils and sediments: II. Chemical weathering of layer silicates. *Soil Sci. Soc. Amer. Proc.* 16: 3-6.
32. Joffe, J. S. 1949. Pedology. 2nd ed. Pedology Publications, New Brunswick, New Jersey.
33. Keller, W. D. 1958. Argillation and direct bauxitization in terms of concentrations of hydrogen and metal cations at surface of hydrolyzing aluminum silicates. *Bull. Amer. Assoc. Pet. Geol.* 42: 233-245.
34. Kelley, W. P. 1948. Cation exchange in soils. Reinhold Pub. Corp., New York, N.Y.
35. Kittrick, J. A. 1961. A comparison of the moving liquid and glass slide methods for the preparation of oriented X-ray diffraction specimens. *Soil Sci.* 92: 155-160.
36. Koltoff, I. M., and E. B. Sandell. 1953. Textbook of quantitative inorganic analysis. 3rd ed. The Macmillian Co., New York, N.Y.
37. Korotkov, A. A. 1960. Modification of Sod-Podzolic soils under meadow vegetation. *Pochvovedenie*. No. 9: 962-968.
38. Lindsay, J. P., S. Pawluk, and W. Odynsky. 1960. Exploratory soil survey of the Alberta map sheets 84-J, 84-L. Preliminary Soil Survey Report 60-1. Research Council of Alberta.
39. Lobova, E. V. 1961. Work of commission V of the International Society of Soil Science at the seventh international soil congress in the U.S.A., 1960. *Pochvovedenie*. No. 3: 327-336.

40. Lutz, H. J., and R. F. Chandler. 1949. Forest soils. John Wiley and Sons, Inc., New York, N.Y.
41. Lyford, W. H. 1947. The morphology of Brown Podzolic soils in New England. Soil Sci. Soc. Amer. Proc. 11: 486-492.
42. Mackenzie, R. C. 1954. Free iron oxide removal from soils. J. Soil Sci. 5: 167-172.
43. Marshall, C. E., and J. F. Haseman. 1942. The quantitative evaluation of soil formation and development by heavy mineral studies: A Grundy profile. Soil Sci. Soc. Amer. Proc. 7: 448-453.
44. McCaleb, S. B., and M. G. Cline. 1949. Profile studies of normal soils of New York: I. Soil profile sequences involving Brown Forest, Gray-Brown Podzolic and Brown Podzolic soils. Soil Sci. 68: 259-272.
45. McCaleb, S. B., and M. G. Cline. 1950. Profile studies of normal soils of New York: III. Physical and chemical properties of Brown Forest and Gray-Brown Podzolic soils. Soil Sci. 70: 315-328.
46. Meeker, E. W., and W. C. Wagner. 1933. Titration of ammonia in presence of boric acid. Ind. Eng. Chem. Anal. Ed. 5: 396-398.
47. Mitchell, B. D., and R. C. Mackenzie. 1954. Removal of free iron oxide from clays. Soil Sci. 77: 173-185.
48. Muckenheim, R. J., E. P. Whiteside, E. H. Templin, R. F. Chandler, and L. T. Alexander. 1949. Soil classification and genetic factors of soil formation. Soil Sci. 68: 93-105.
49. Munsell soil color charts. 1946. Munsell Color Co. Inc., Baltimore, Maryland, U.S.A.
50. National Soil Survey Committee of Canada. 1960. Report of meetings held at the Ontario Agricultural College, Guelph, Ontario.
51. Nikiforoff, C. C. 1949. Weathering and soil evolution. Soil Sci. 67: 219-230.
52. Nygard, I. J., P. R. McMiller, and F. D. Hole. 1952. Characteristics of some Podzolic, Brown Forest and Chernozemic soils of the northern portion of the lake states. Soil Sci. Soc. Amer. Proc. 16: 123-129.

53. Odynsky, W., J. D. Lindsay, S. W. Reeder, and A. Wynnyk. 1961. Soil survey of the Beaverlodge and Blueberry Mountain sheets. Univ. of Alta. Bull. SS-3.
54. Odynsky, W., and J. D. Newton. 1950. Soil survey of the Rycroft and Watino sheets. Univ. of Alta. Bull. 53.
55. Parfenova, Y. I., and Y. Yarilova. 1960. The problem of lessivage and podzolization. Pochvovedenie. No. 9: 913-925.
56. Pawluk, S. 1960. Characteristics of Grey Wooded soils developed from glacial till deposits in Peace River districts and north central regions of Alberta. Trans. 7th Intern. Congr. Soil Sci. Vol. IV: 314-322.
57. Pawluk, S. 1960. Some Podzol soils of Alberta. Can. J. Soil Sci. 40: 1-5.
58. Pawluk, S. 1961. Mineralogical composition of some Grey Wooded soils developed from glacial till. Can. J. Soil Sci. 41: 228-240.
59. Pawluk, S., and C. F. Bentley. 1956. Exchangeable cation characteristics of some west central Alberta soils. Can. J. Agr. Sci. 36: 380-389.
60. Rieger, S., and R. L. Juve. 1961. Soil development in recent loess in the Matanuska Valley, Alaska. Soil Sci. Soc. Amer. Proc. 25: 243-248.
61. Rozanov, A. N. 1956. Grey-brown soils as particular type of soil. Trans. Intern. Congr. Soil Sci. 6th Congr. Paris E: 169-174.
62. Russell, E. W. 1961. Soil conditions and plant growth. 9th ed. Longmans, Green and Co., 137 Bond Street, Toronto, Ontario.
63. Sigmond, A. A. J. de. 1938. The principles of soil science. Thomas Murphy and Co., London.
64. Simonson, R. W. 1959. Outline of a generalized theory of soil genesis. Soil Sci. Soc. Amer. Proc. 23: 152-156.
65. Soil Survey Staff, U.S. Dept. of Agr. 1960. Soil classification, 7th approximation. Washington, D.C.
66. Solov'yev, P. Y. 1961. Change in the physical properties of ordinary Chernozems under the effect of forest vegetation. Doklady, Soil Sci. Sec. 29-33.

67. Stobbe, P. C. 1952. The morphology and genesis of the Gray-Brown Podzolic and related soils of eastern Canada. *Soil Sci. Soc. Amer. Proc.* 16: 81-84.
68. Stobbe, P. C., and J. R. Wright. 1959. Modern concepts of the genesis of Podzols. *Soil Sci. Soc. Amer. Proc.* 23: 161-163.
69. Tavernier, R., and Guy D. Smith. 1957. The concept of Braunerde (Brown Forest soil) in Europe and the United States. *Adv. in Agron.* 9: 217-289.
70. Thorp, J., J. G. Cady, and E. Gamble. 1959. Genesis of Miami silt loam. *Soil Sci. Soc. Amer. Proc.* 23: 156-161.
71. Thorp, J., and Guy D. Smith. 1949. Higher categories of soil classification: Order, Suborder and Great Soil group. *Soil Sci.* 67: 117-126.
72. Theisen, A. A., and M. E. Harward. 1962. A paste method for preparation of slides for clay mineral identification by X-ray diffraction. *Soil Sci. Soc. Amer. Proc.* 26: 90-91.
73. Theisen, A. A., G. R. Webster, and M. C. Harvard. 1959. The occurrence of chlorite and vermiculite in the clay fraction of three British Columbia soils. *Can. J. Soil Sci.* 39: 244-251.
74. Toogood, J. A., and T. W. Peters. 1959. Comparison of mechanical analysis of soils. *Can. J. Agr.* 33: 159-171.
75. U.S.D.A. 1954. Diagnosis and improvement of saline and alkali soils. L. A. Richard ed. *Agr. Handb. No. 18.* U.S. Gov't. Printing Office, Washington, D.C.
76. U.S.D.A. 1951. Soil survey manual. *Handb. No. 18.* U.S. Gov't. Printing Office, Washington, D.C.
77. Weaver, C. E. 1958. Geologic interpretations of argillaceous sediments. *Bull. Amer. Assoc. Petrol. Geol.* 42: 254-309.
78. White, E. M., and F. F. Riecken. 1955. Brunizem - Gray - Brown Podzolic soil biosequences. *Soil Sci. Soc. Amer. Proc.* 19: 504-509.
79. White, J. L. 1951. Transformation of illite into montmorillonite. *Soil Sci. Soc. Amer. Proc.* 15: 129-133.

80. Wright, J. R., A. Leahay, and H. M. Rice. 1959. Chemical, morphological and mineralogical characteristics of a chronosequence of soils on the alluvial deposits in the Northwest Territories. *Can. J. Soil Sci.* 39: 32-44.
81. Van der Marel, H. W. 1950. Identification of minerals in soils by X-ray diffraction. *Soil Sci.* 70: 109-136.
82. Vilenski, D. C. 1957. Soil science. States Teachers Col. Publ. House. Ministry of Culture, Russian Soc. Fed. Soviet Rep. Moscow.
83. Zaytsev, D. D. 1960. Characteristics of northwest Caucasian Brown Forest soils. *Pochvovedenie.* No. 12: 1327-1333.
84. Zoon, S. V., and I. I. Feoprova. 1960. A new group of soils under dark coniferous forests in Tibet. *Pochvovedenie.* No. 6: 585-592.

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